Borrower is requested to check the book and get the signatures on the torned pages, if any.

BASIC ELECTRICITY AND
ELECTRONICS TRAINING

BASIC ELECTRONICS

VOLUME 1
of 6 volumes

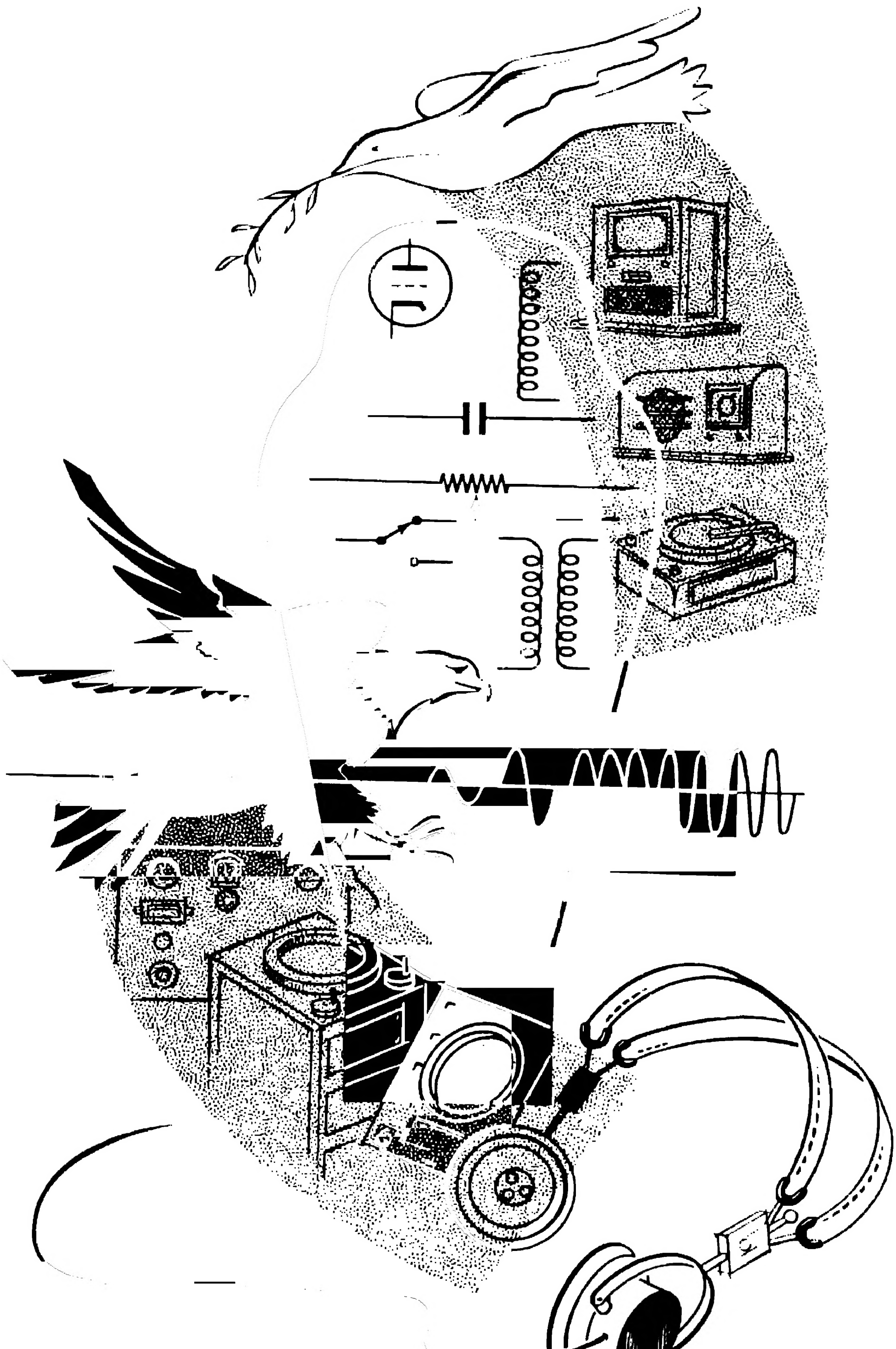
This volume contains Trainee
Information, Demonstration, and
Experiment Instruction sheets for:

Section I Introduction to Electronics
Section II Power Supplies

BASIC ELECTRONICS

Table of Contents

Consists of six volumes of Trainee Information, Demonstration and Experiment Instruction Sheets covering the following:



Introduction to electronics

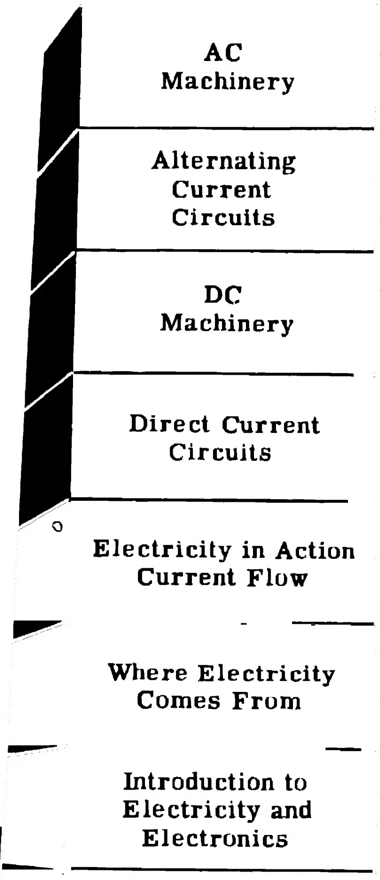
SECTION I

introduction to ELECTRONICS

What You Are Going To Do Now

You now have a good solid foundation in the field of electricity. You know how electricity is generated, how electron current flows through a circuit, the nature and uses of magnetism, the proper use and care of meters, the characteristics of DC and AC and how various types of electrical motors and other electrical devices operate.

Now you have all the fundamental knowledge that you need to begin your study of a new and fascinating subject—electronics.

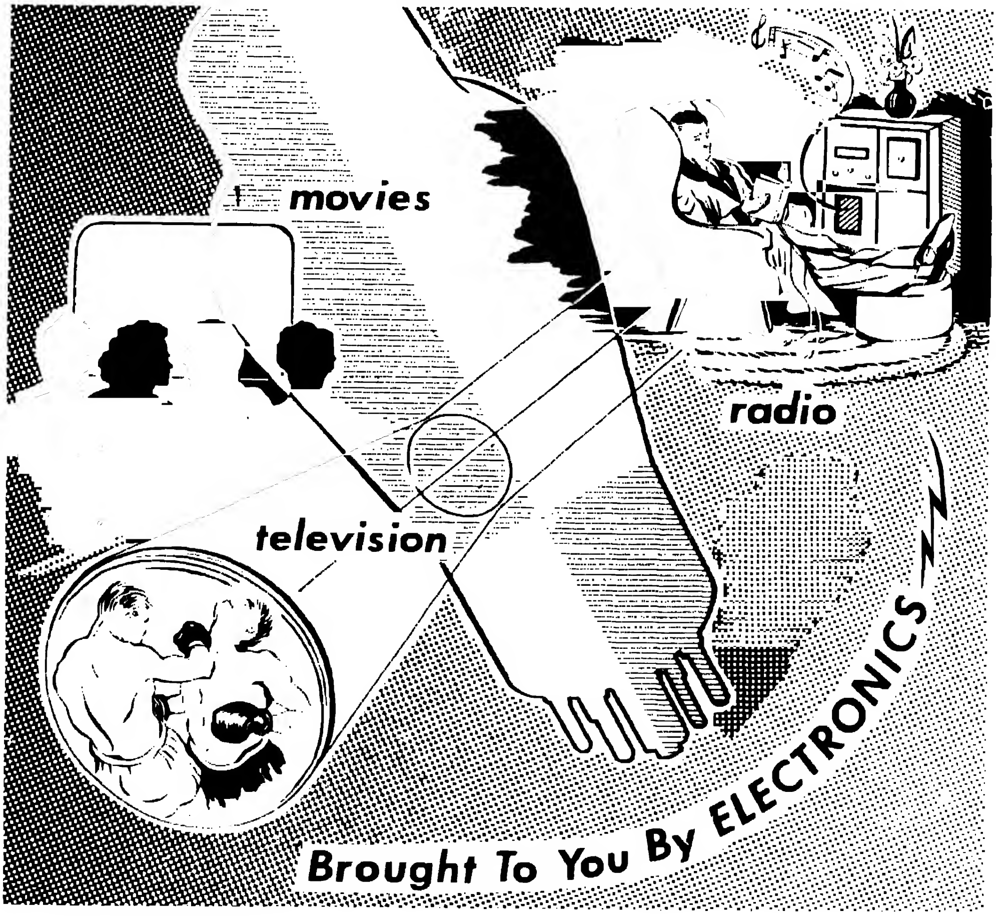


INTRODUCTION TO ELECTRONICS

The Meaning of "Electronics"

You have heard the word "electronics" many times in the past. Electronics means the science of the electron. Since the study of electricity and electronics both involve the use of the concept of electron flow, you may wonder where electricity ends and electronics begins. For your purposes it is easy enough to make the distinction that electronics is the science which is concerned with the flow of electrons through vacuum or gas-filled tubes sometimes called "electron tubes." Thus, electronics includes the study of any equipment that contains "tubes."

You are already acquainted with quite a few types of electronic equipment. Radio—"talkie" motion pictures—record players—public address systems—television—"electric eye" door openers—all of these make use of "tubes" and are correctly termed electronic equipment. Of course they also make use of various types of DC and AC circuits, of meters, transformers, capacitors, and all the other components which you have learned about in Basic Electricity. That is why you needed a course in fundamentals before going on with the electronics phase of your study.



INTRODUCTION TO ELECTRONICS

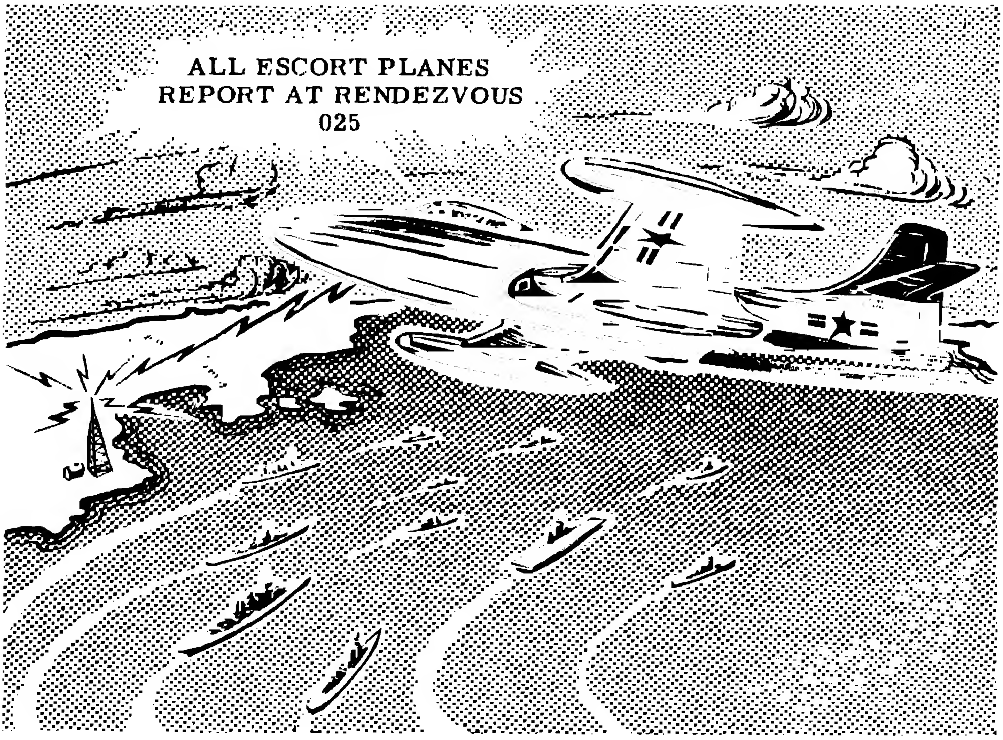
How the Navy Uses Electronics

The Navy has many uses for electronic equipment. This type of equipment includes radio, intercom, radar, sonar, loran and remote metering equipment. Also included are certain special types of mines and torpedoes. Suppose you make a brief survey of how the Navy uses electronics in these various applications.

Radio Transmitters and Receivers

In the Navy the ships, planes and submarines do not act independently of one another but operate rather as a team working together to accomplish a specific task. Radio equipment—transmitters and receivers—is used to coordinate the activities of the many units in the Fleet by linking them with each other and with shore stations. Success in naval operations is very largely dependent upon the operation of the radio equipment since almost all the battle information sent between various units goes by way of radio.

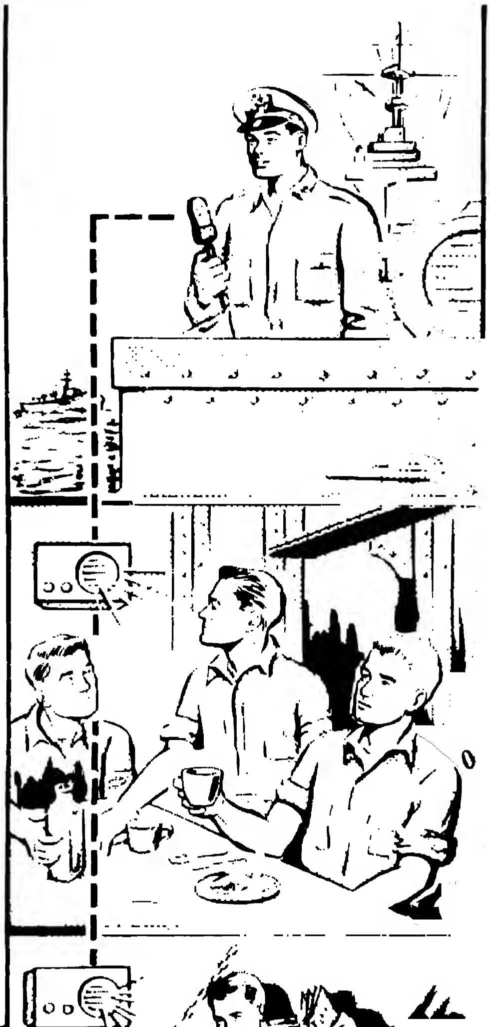
With the assistance of radio equipment, tenders meet other Navy units in mid-ocean, convoys are formed and directed, units join to form invasion fleets, enemy coasts are bombarded, and landing operations are coordinated. It is the responsibility of the RM and ET to properly operate, maintain and troubleshoot radio transmitters and receivers in the Navy.



INTRODUCTION TO ELECTRONICS

Interior Communications and Remote Metering

Just as radio equipment serves to maintain contact between the Navy's many ships and shore stations, intercoms and remote metering systems are used to send information between the various parts of each ship. In order for a ship to function properly, information must be transmitted from and orders issued to each portion. Besides the transmission of voice messages, there are instrument readings that must be transmitted between various points of the ship. The speed, bearing, angle of roll and pitch of the ship, wind velocity, air and water temperature, salt content of the ocean, etc. are of major importance in many operations. This information is transmitted by means of remote metering systems to the various interested activities. Proper navigation, accurate aiming of the ship's guns, accurate submarine location and other vital activities depend upon this information. Without intercom and remote metering systems your ship would cease to be a smoothly operating unit of the Fleet. The IC rate is responsible for the proper operation and maintenance of this equipment.

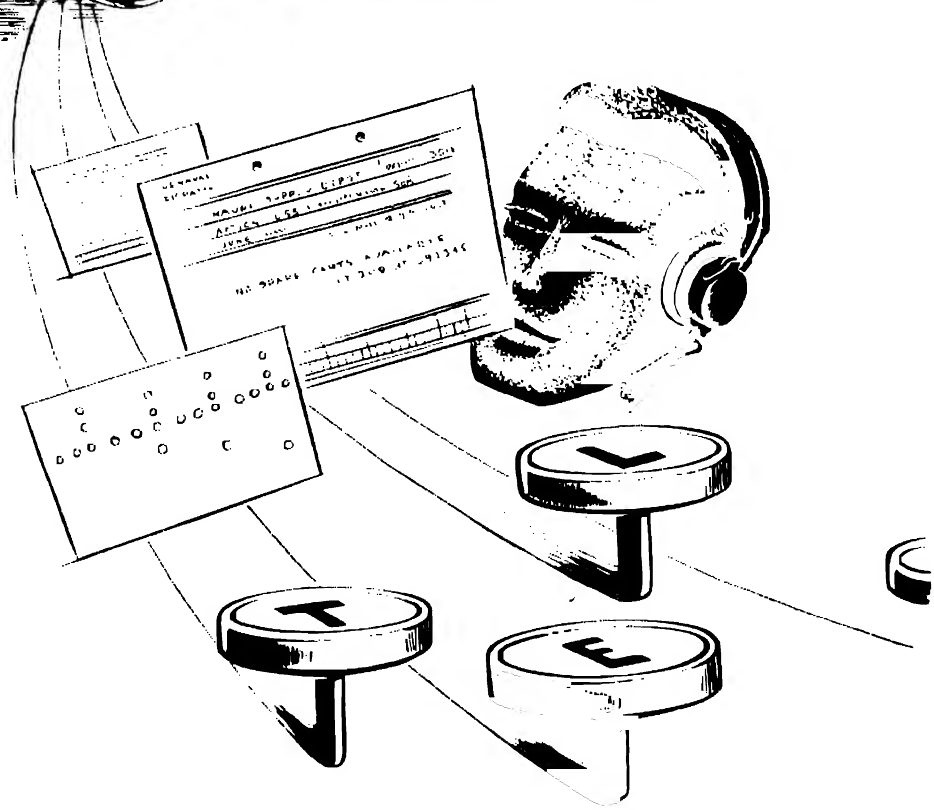


INTRODUCTION TO ELECTRONICS

Radio Teletype

For some time the Navy radio communications system was adequate to transmit all the Navy's messages. However, as the Navy continued to grow, the need for transmitting and receiving messages became greater than could be handled by radio alone. Teletype is the answer to the necessity of providing a quick, accurate method of receiving written copies of dispatches at the same time in many different places. Through the use of the latest developments in teletype equipment, the Navy has established the NTX (naval teletypewriter system) which has landlines and overseas radio trunks and makes up a large part of the Navy Shore Communication System. In addition there is the RATT (radio teletypewriter) system which is used aboard ships of the Fleet.

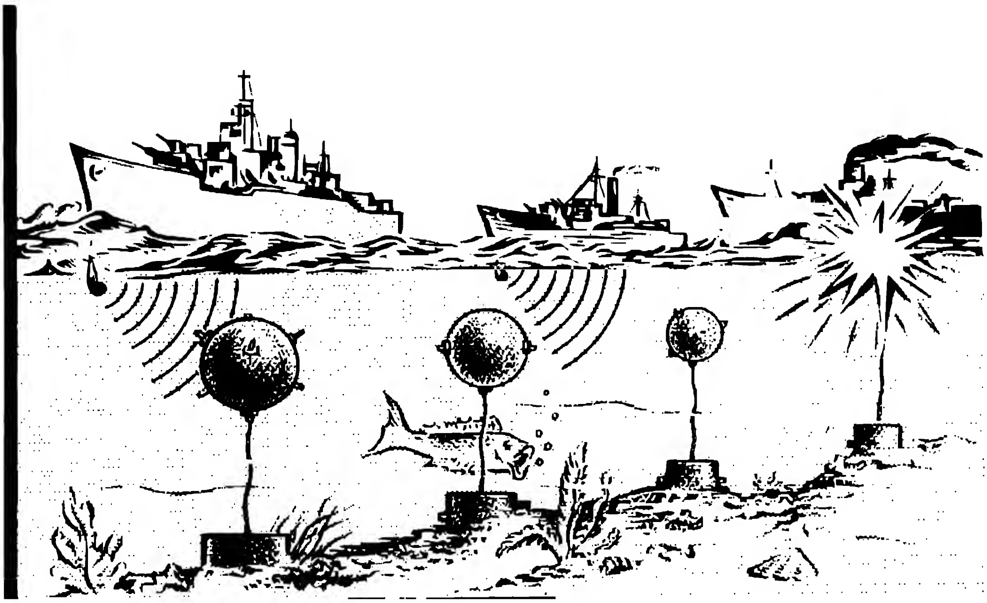
This whole system of communication is the TE's specialty. The teleman transmits and receives Navy communications on the teletype and voice radio equipment. In order to keep this equipment in first class operating condition the TE must have a good understanding of the principles of electronics.

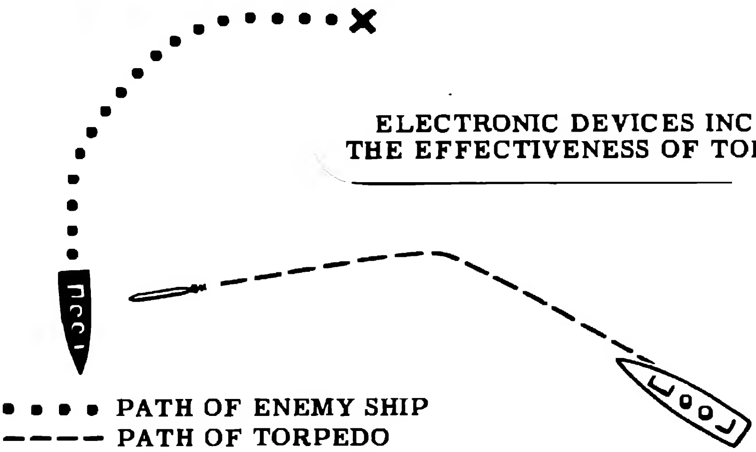


INTRODUCTION TO ELECTRONICS

Electronic Mines and Torpedoes

Certain special mines and torpedoes also make use of electronic equipment. Modern mines contain listening devices and other devices which cannot be mentioned here. It should be enough to say that these mines will go off underneath an enemy ship at exactly the right time and that they cannot be set off by the enemy before the proper time. Certain modern torpedoes contain electronic devices which enable the torpedo to detect the enemy ship and aim itself straight at that ship while correcting for any evasive tactics the enemy may make. These special mines and torpedoes depend on the MN and TM rates for proper operation and maintenance.

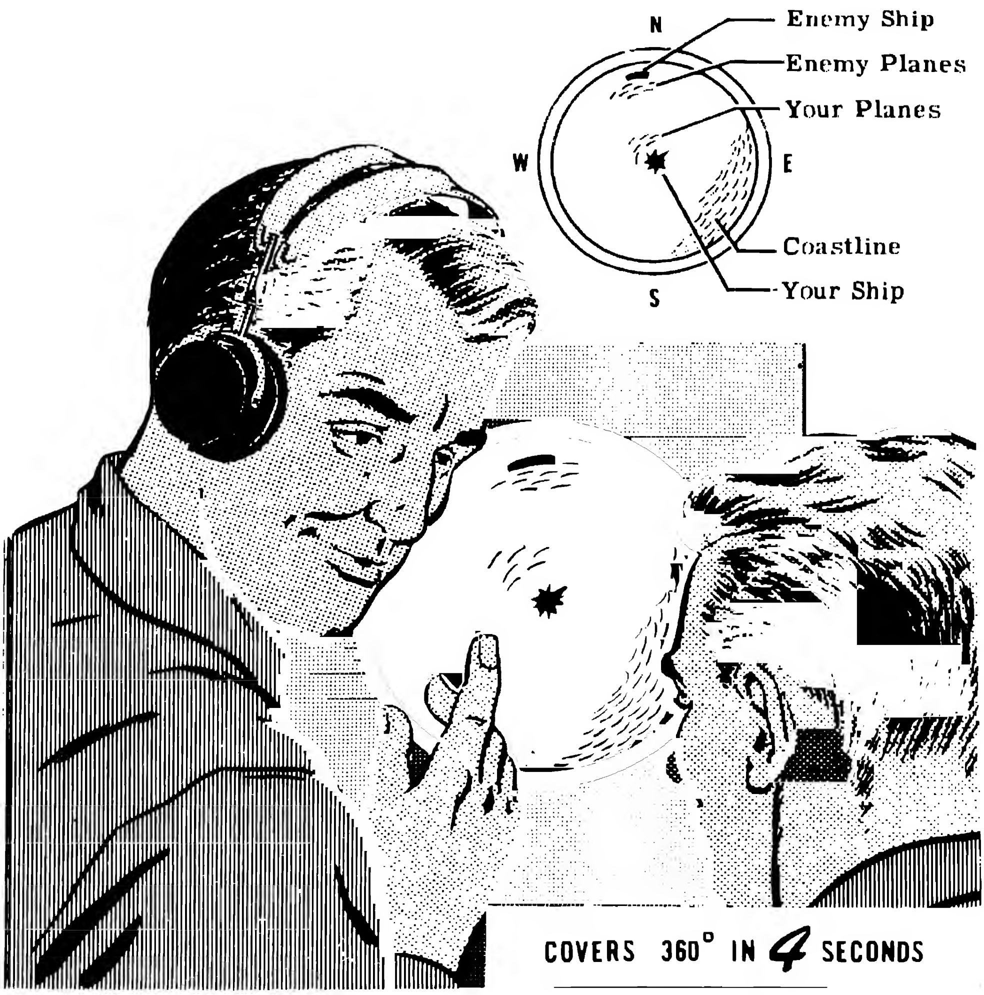




ELECTRONIC DEVICES INCREASE THE EFFECTIVENESS OF TORPEDOES

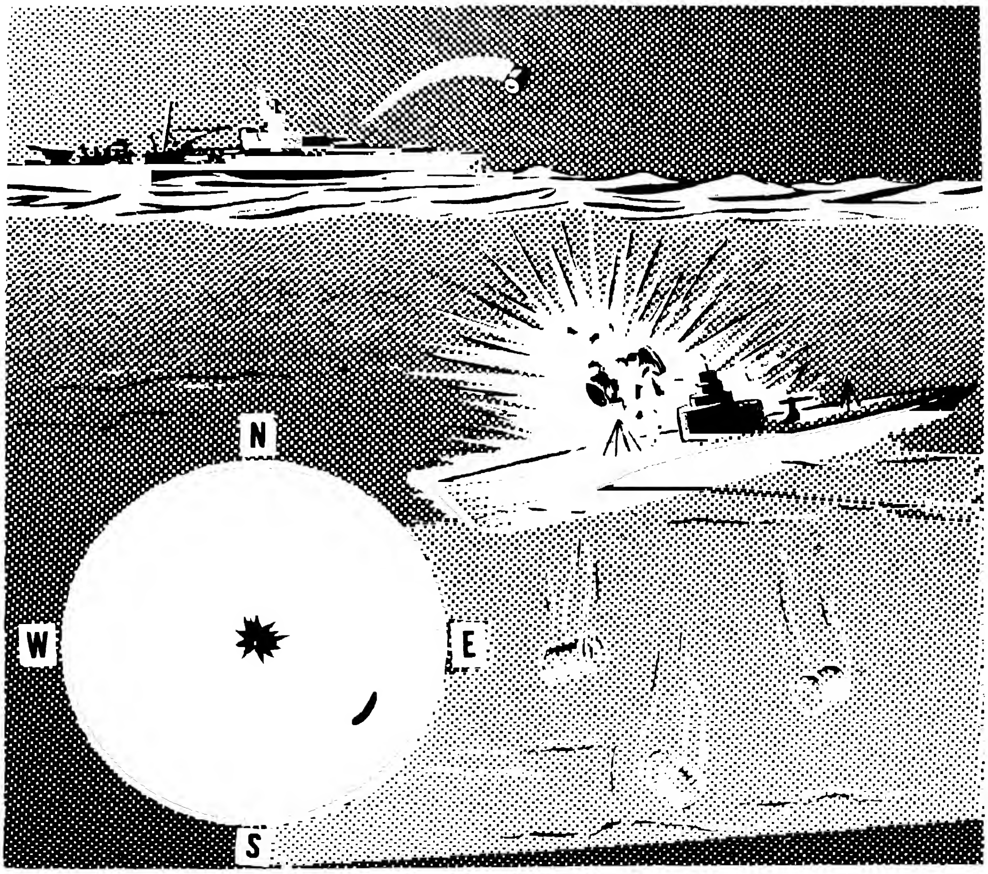
Radar

At some time or other, you have all heard of radar. Radar was perfected during World War II and was rated the most important scientific development next to the atom bomb. Radar equipment enables you to detect all the ships, planes and surfaced submarines in a large area around your ship. You can actually see these ships and planes on a screen and tell their range, bearing and the direction in which they are headed. You can see them through darkness, fog and rain, and you always know whether they are friendly or enemy. Radar gives you advance warning of any move the enemy craft may make. Radar enables every ship to keep in proper position during Fleet or convoy maneuvers, and it gives vital information as to the presence of land whenever a ship is operating close to shore. Radar is the long distance eye of the ship—its proper operation and maintenance is the responsibility of the RD and ET rates.



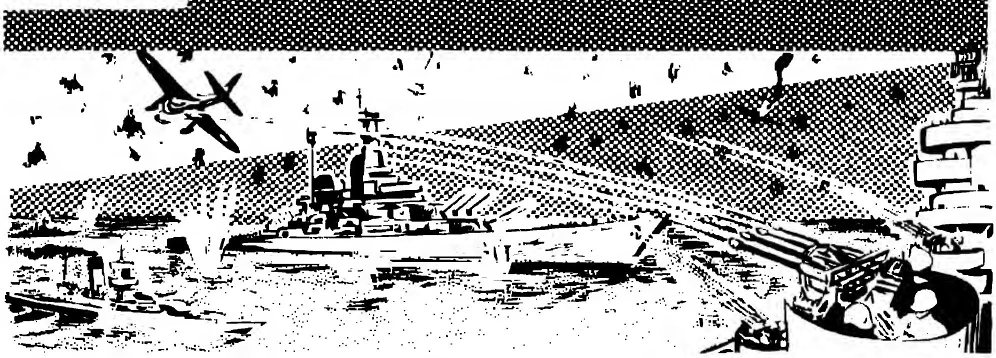
Sonar

Sonar is the equivalent of underwater radar. Radar makes use of high frequency radio waves to detect enemy ships and planes. However, radio waves will not travel through water, so sonar makes use of high frequency sound waves in order to determine what is happening in a large area under the surface of the ocean. Modern sonar equipment shows you an underwater map of the ocean around your ship. Other ships, submarines, reefs, schools of fish and mines all appear as indications on a screen which shows their range, bearing and relative motion. While sonar can be used for underwater communication between ships and submarines and is a very important aid to navigation, the main purpose of sonar is to locate and destroy enemy submarines. Sonar detects enemy submarines, measures all of the many factors to be considered in getting a correct knowledge of range, bearing and depth; and sonar tells you the exact instant you are in the correct position to fire your depth charges. It is the responsibility of the SO and ET rates to properly operate and maintain Navy sonar equipment.



INTRODUCTION TO ELECTRONICS

Fire Control



The purpose of a fire control system is to aim the ship's guns so that the shells land right on the target. Some types of fire control systems are designed to be used against surface targets, and other types are designed for antiaircraft purposes. At present fire control systems are beginning to be used with certain types of sonar equipment.

Fire control systems have shown remarkable improvement in the last 200 years. Less than 200 years ago the target had to be from 20 to 50 yards from the gun before it was reasonably certain that a hit would be made. During the War Between the States, this range went up to one mile— although the average operating range was 100 yards. After World War I it was possible to score hits on enemy vessels at 24,000 yards. During World War II fire control systems were designed to include radar and other electronic equipment.

Now, because of electronic equipment, hits can be scored against enemy targets at distances of more than 40,000 yards. These hits can be scored even though you cannot see the target from your ship—night, rain, fog and other conditions causing poor visibility do not prevent hits from being made. In modern fire control systems, electronic equipment locates the target, measures all the factors that must be considered, calculates how the guns should be aimed, controls the gun-aiming machinery and fires the guns at exactly the right instant.

It is the responsibility of the FT rate to properly operate and maintain Navy fire control equipment.

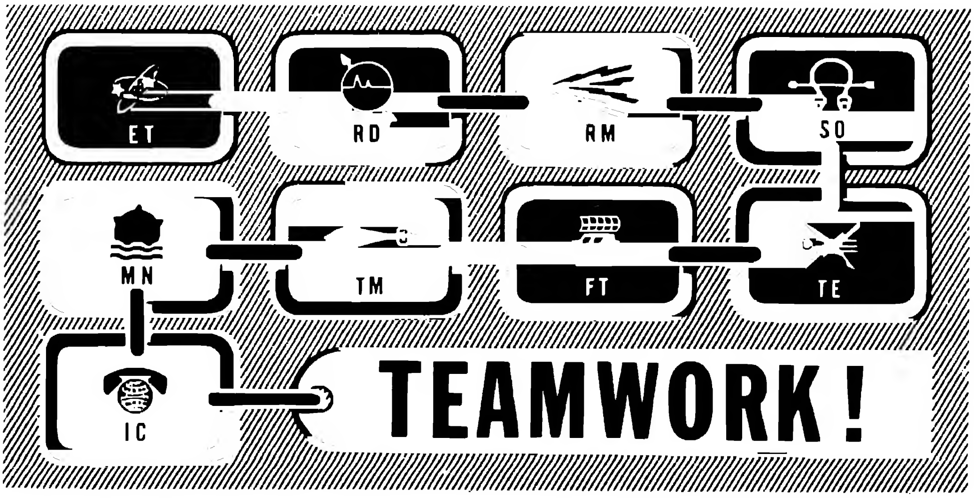
INTRODUCTION TO ELECTRONICS

Your Job in Electronics

None of the equipments just described can operate itself or keep itself cared for and repaired. The proper functioning of each piece of equipment depends completely upon the "know-how" of the operator and technician assigned to it. Without the services of the operator and technician all Navy electronic equipment would be just so much scrap metal whose space and weight could better be replaced by fuel oil tanks.

The pictures on radar, sonar and fire control 'scope screens mean nothing to an untrained person. The operators of this equipment must learn the meaning of what they see on the screen and they must transmit this information to others who will take a course of action depending upon what the operator sees. Radio code messages coming in at 20 or 25 words per minute would be just so much noise to the average person. Only the RM can tell what these signals mean. Electronic torpedoes and mines are complicated devices. Without an experienced operator to adjust them before they are fired or dropped over the side, they will not do the job they were designed to do.

Not only must the operator know how to run his equipment but he must also know how it works so that he can service and troubleshoot it. Without proper servicing, a piece of equipment will not operate at its top efficiency; its operation will become worse and worse and eventually it will not work at all. Each operator, therefore, must learn how to care for his equipment and how to keep it in proper adjustment. In addition to operating and servicing duties, each rate must know how to repair his equipment when something goes wrong. Many types of troubles may occur in electronic equipment—tubes may go bad, resistors may burn out, capacitors may develop an internal "open" or "short," etc. Each rate must learn how to locate these troubles and replace the defective part in his equipment.



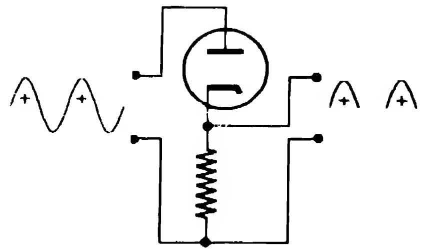
INTRODUCTION TO ELECTRONICS

Electronic Equipment

After reading the sheets describing the general types of electronic equipment the Navy uses, you may have the idea that there are so many that you would have to be a mad scientist before you could even begin to find your way around in electronics. This is definitely not true. All electronic equipment is made up of only a few basic circuits. Just how many basic types of circuit are there? Three! Are there any other types you will ever have to know? If your rate is one involved with radar or sonar, there are three additional types of special circuits you will have to learn when you begin to study that equipment, but these special circuits are nothing but variations of the three basic electronic circuits.

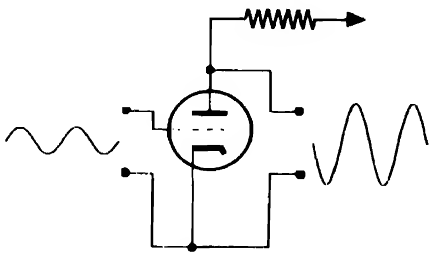
The three basic electronic circuits are rectifier circuits, amplifier circuits and oscillator circuits.

RECTIFIER CIRCUIT



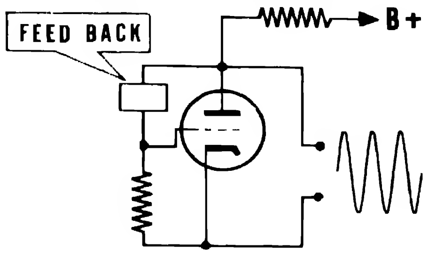
Rectifier circuits change AC to DC. Their most common use is in electronic equipment power supplies which take AC from the power line and transform it to DC which is required to operate electron tubes.

AMPLIFIER CIRCUIT



Amplifier circuits take small voltage changes and enlarge or amplify them into large voltage changes. Amplifier circuits are by far the most commonly used circuits in electronic equipment. They take very weak signals that are barely detectable and amplify them into strong signals that can drive a pair of earphones, a loudspeaker or an oscilloscope.

OSCILLATOR CIRCUIT

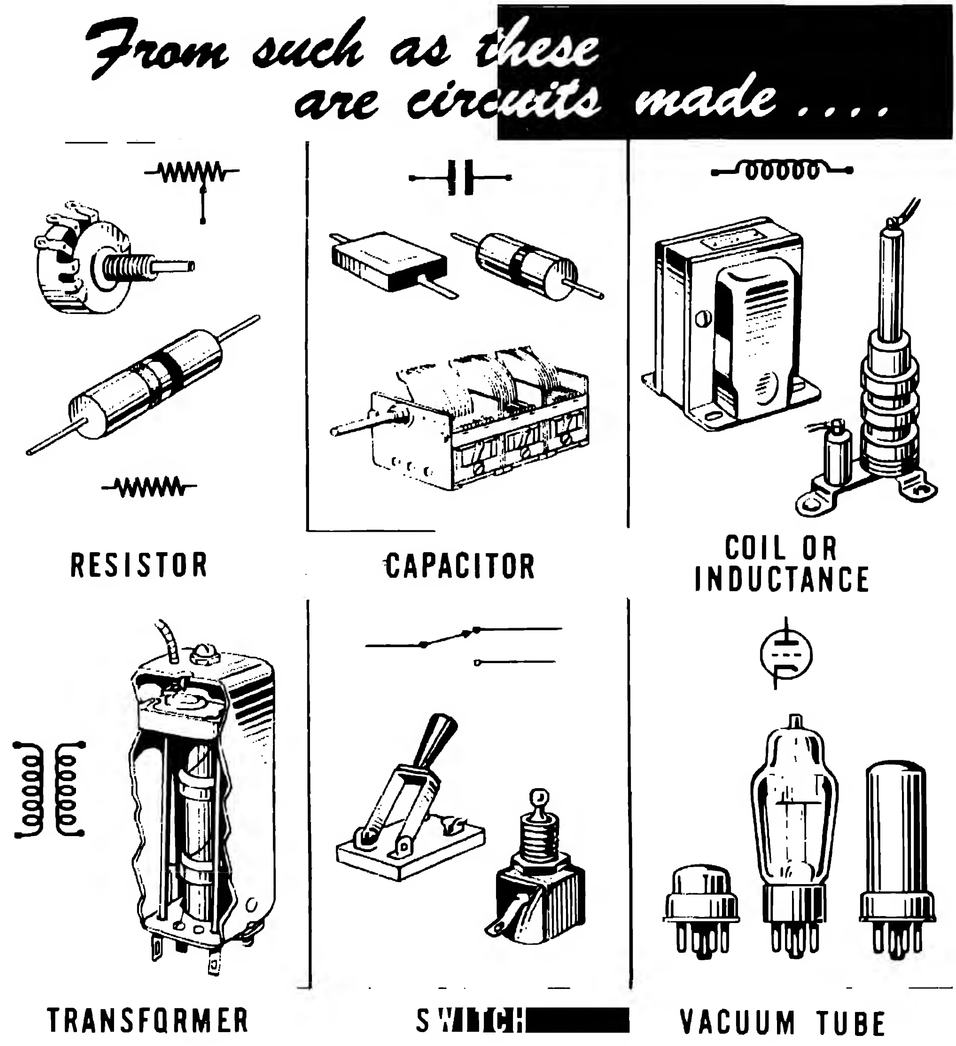


Oscillator circuits generate AC voltages at any particular desired frequency. Oscillator circuits are used to generate the AC voltages that carry a radio signal from one place to another. They are also used very extensively for testing other electronic circuits.

Parts Used in Electronic Equipment

Now that you have found out that there are only three basic types of electronic circuits (rectifiers, amplifiers and oscillators) that you have to be concerned with, you probably would like to know about the parts used in those circuits. Actually there are only six commonly used types of parts in electronic circuits. Five of these parts you already know—resistors, capacitors, coils, transformers and switches. There is one additional type of part that you will learn about very soon—"vacuum tubes."

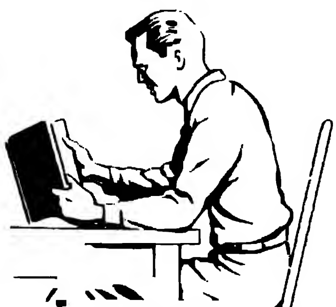
You see that by understanding three basic types of electronic circuits and the use of six types of parts in those circuits, you will understand all you need to know about electronics for the present.



INTRODUCTION TO ELECTRONICS

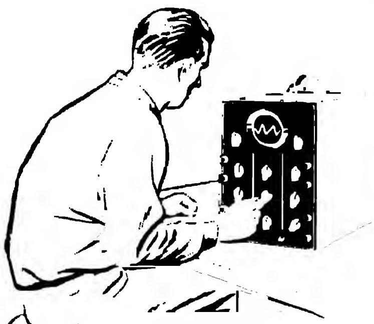
How You Are Going to Learn Electronics

You learned Basic Electricity by the Craftsman method which includes reading, discussion, demonstration and practical work. You are going to learn about electronics in very much the same way, except that more and more stress is going to be put on practical work. Your practical work will consist of working with circuits similar to those found in real Navy Equipment. You will build these circuits, observe how they work and get plenty of practice in troubleshooting them.

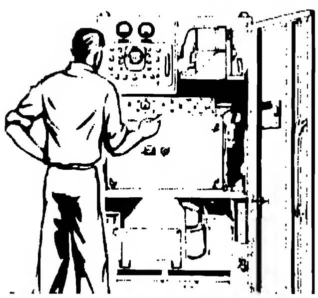


READING

BUILDING



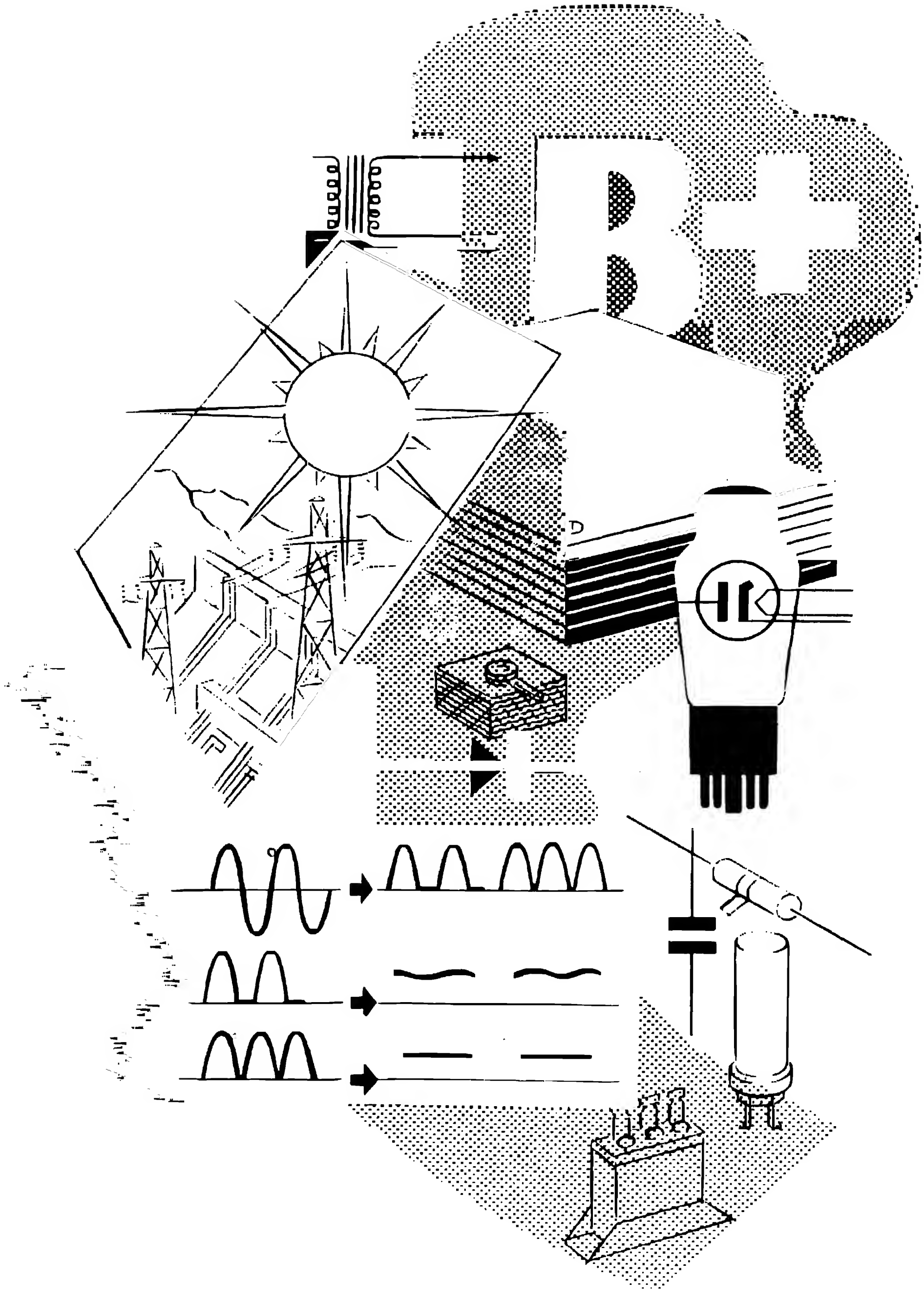
OBSERVING



TROUBLESHOOTING

Of all the things you are going to do, troubleshooting is the most important by far. It doesn't do the Navy any good if you can give a learned lecture on how a circuit works. The payoff is when you can fix something that goes wrong.

In this Introduction to Electronics you have read that there are three basic types of circuits—rectifiers, amplifiers and oscillators—which are used to make up the major portion of nearly every bit of electronic equipment you will find in the Navy. You are going to learn about electronics by working with these circuits as they are used in this equipment. The circuit that will be the easiest for you to begin with is the rectifier circuit which is used in the power supply portion of practically every piece of Navy electronic equipment. By beginning your work in electronics with "Power Supplies" you will learn all you need to know about rectifier circuits.



Power Supplies

SECTION II

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BASIC ELECTRONICS

Topic Outline of Section II

POWER SUPPLIES

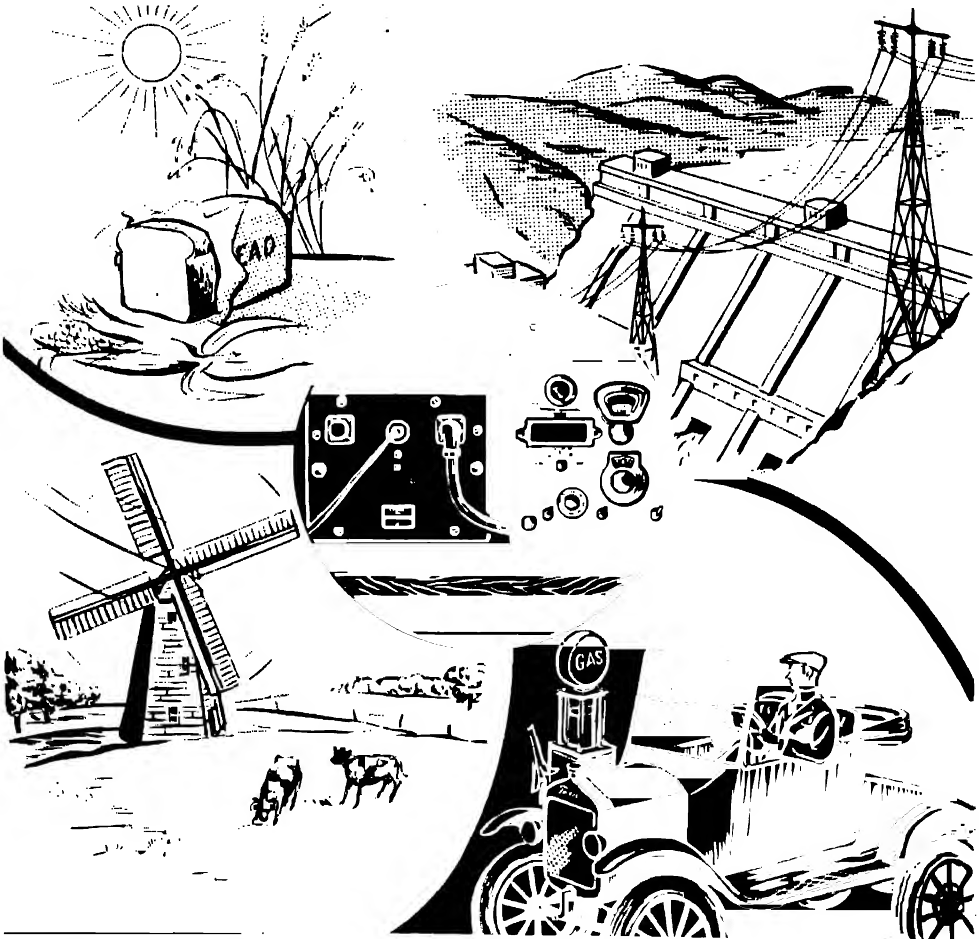
Information-Demonstration-Experiment Sheets

WHAT A POWER SUPPLY IS

Importance of Power Supplies

Everything that lives or does work must have a source of power or a "power supply." The sun supplies power that enables plants to manufacture food, and food in turn supplies the power that makes you live and move, - speak, run, and think. In the realm of non-living mechanisms, the motor in the old Model "T" supplied power to move the car as surely as the huge turbines at Boulder Dam supply power today to drive electric generators.

It is obvious that the same kind of power is not used in the same way in these different cases. Each thing—large or small, living or non-living—must take its power from a primary source such as the sun, falling water, or an electric light socket and change it into the specific kind of power needed. In electronics, then, a "power supply" is a circuit or device that changes the primary electric power into the kind and amount of AC or DC needed by different types of electronic circuits.



Everything needs its **POWER SUPPLY**

WHAT A POWER SUPPLY IS

What Power Supplies Do

All electronic equipment that you will find installed aboard ship or in a shore station will have a power supply to transform the AC line voltage into DC and low voltage AC. Since the electronic equipment will not operate unless it has these required voltages, it is most important for you to learn how power supplies work and how to troubleshoot them. Power supplies are simple circuits—often containing only one rectifier tube. The troubles that can occur in a power supply are very few, but unless you know how to locate and repair that trouble very quickly a vital piece of equipment will be out of operation.

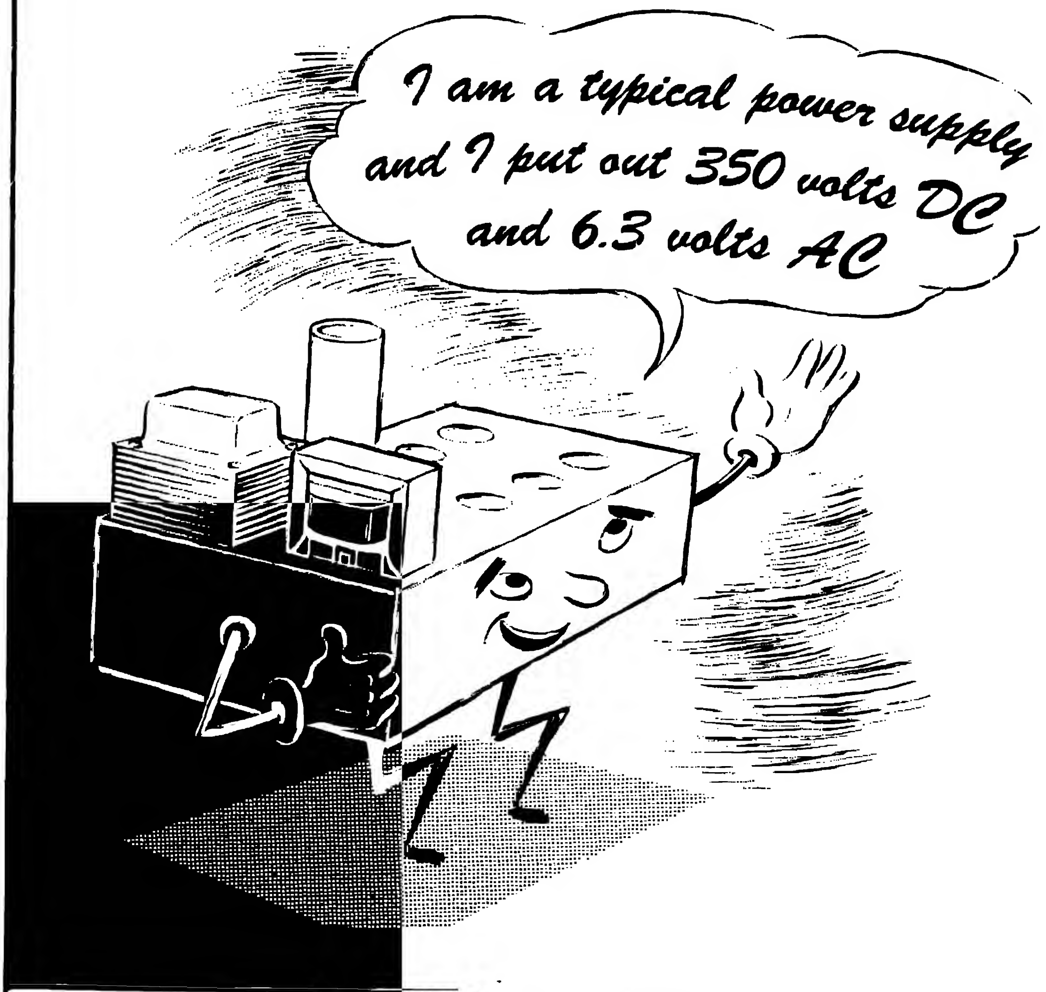
Radio, teletype, intercommunications systems, radar, sonar, fire control, underseas weapons—all these different equipments which perform very different jobs, have power supplies. All these power supplies, although they differ in details, operate on the same basic principles. To work with electronic equipment, and to keep your equipment operating, you must know how power supplies work and how to troubleshoot them.

WHAT A POWER SUPPLY IS

What Power Supplies Do (continued)

Let's get down to cases and find out just what a power supply is supposed to do. Different types of electronic equipment—amplifiers, oscillators, transmitters and receivers—contain different types of vacuum tube circuits which must have certain AC and DC voltages supplied to them before they can operate. While there are exceptions, in general these various vacuum tube circuits require approximately 350 volts DC and 6.3 volts AC. Just why these two voltages are required is something you will learn when you come to study these circuits. For the present it is enough for you to know that the usual power supply must put out these voltages.

When you plug any piece of electronic equipment into an electric outlet, that outlet puts out 117 volts AC. That is not what you want—the vacuum tube circuits usually must have 350 volts DC and 6.3 volts AC. How a power supply changes the available line voltage into the high DC voltage (called "B+" voltage in all electronics work) and low AC voltage is the major subject of this section.

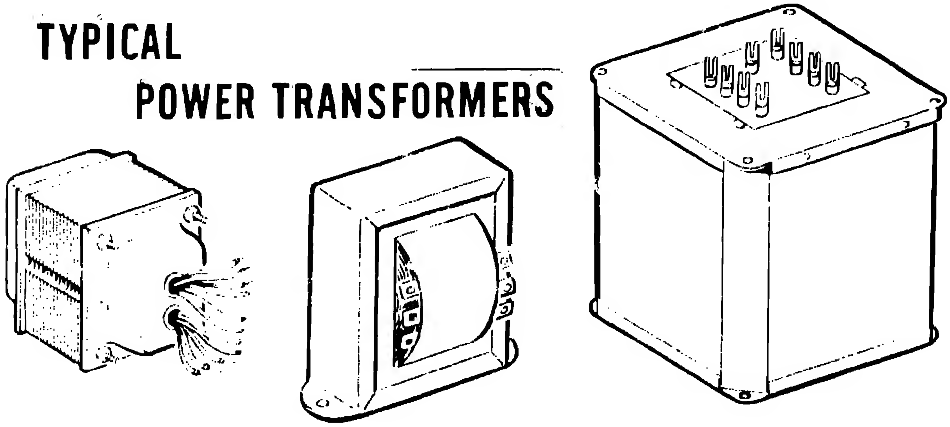


WHAT A POWER SUPPLY IS

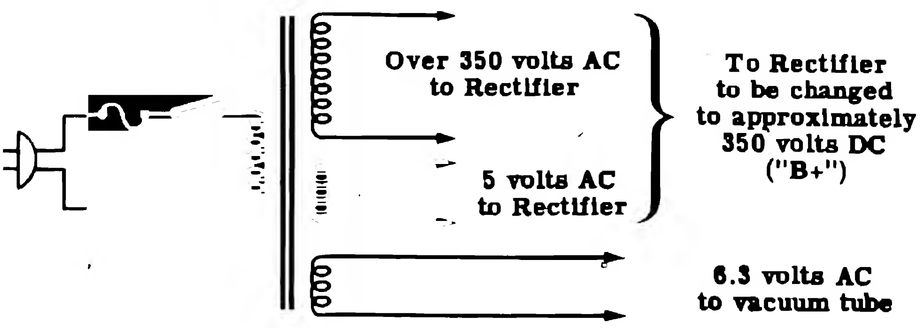
How a Power Supply Works—The Transformer

A typical power supply consists of three major components—a transformer, a rectifier and a filter.

You already know about transformers from your work in basic electricity. A transformer is a device made up of two or more coils of wire wound on an iron core. Transformers can take an AC voltage and increase it or decrease it depending upon the number of turns of wire in the various windings. Here are a few examples of transformers that you will find in electronic equipment power supplies.



In a typical power supply the transformer is connected to the 117-volt AC power line through a suitable fuse and switch. The transformer puts out three AC voltages—a voltage somewhat higher than 350 volts AC, 5 volts AC and 6.3 volts AC. The 6.3 volt AC output is connected directly to the vacuum tube circuits. The other two voltages are connected to the rectifier circuit where the high voltage AC is changed to approximately 350 volts DC. More than 350 volts AC are required to get 350 volts DC because of losses that occur in the process of changing AC to DC, so you must begin with a higher voltage than you want to take out.



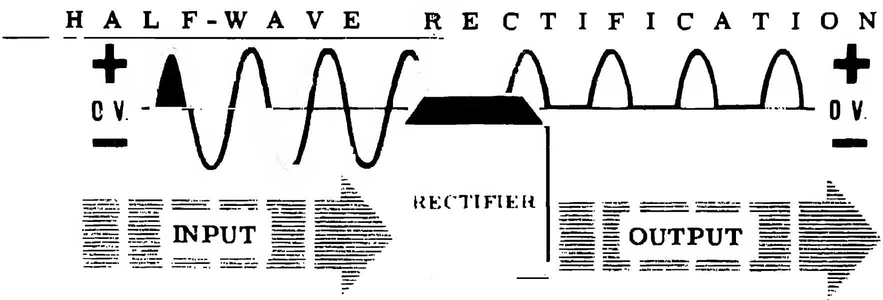
WHAT A POWER SUPPLY IS

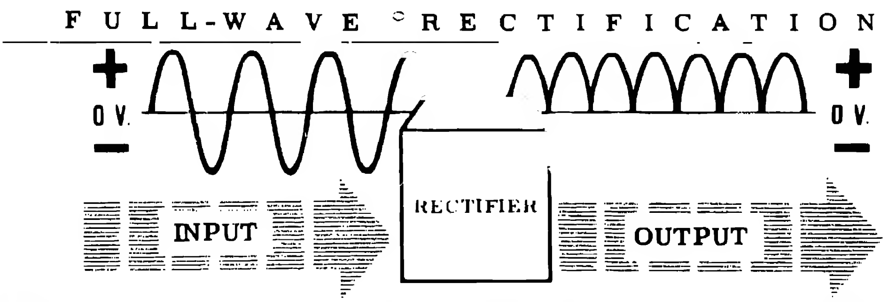
How a Power Supply Works—The Rectifier

Up to now you have learned that the job of a typical power supply is to take 117 volts AC from the power line and to put out approximately 350 volts DC and 6.3 volts AC. You have learned that the major components of a power supply are a transformer, a rectifier and a filter circuit; and you have found out about the job of the transformer.

The job of the rectifier is to change the high voltage AC coming out of the transformer into high voltage DC. The 5-volt AC voltage coming out of the transformer is used to heat the rectifier tube, when such a type of rectifier is used. The 5-volt AC winding is eliminated from the transformer when it is not required for the operation of the rectifier.

The job of changing high voltage AC into high voltage DC is a difficult one. All the rectifier can do is to change the AC into pulsating DC like this:





Notice that the DC output is not a constant voltage but rises and falls in time with the AC voltage input. When only the positive half cycles of the input voltage are allowed to pass through the rectifier and the negative half cycles cannot pass through at all, the process is called "half-wave rectification."

When the positive half cycle of the input voltage is allowed to pass through the rectifier and the negative half cycles are changed to positive half cycles, the process is called "full-wave rectification."

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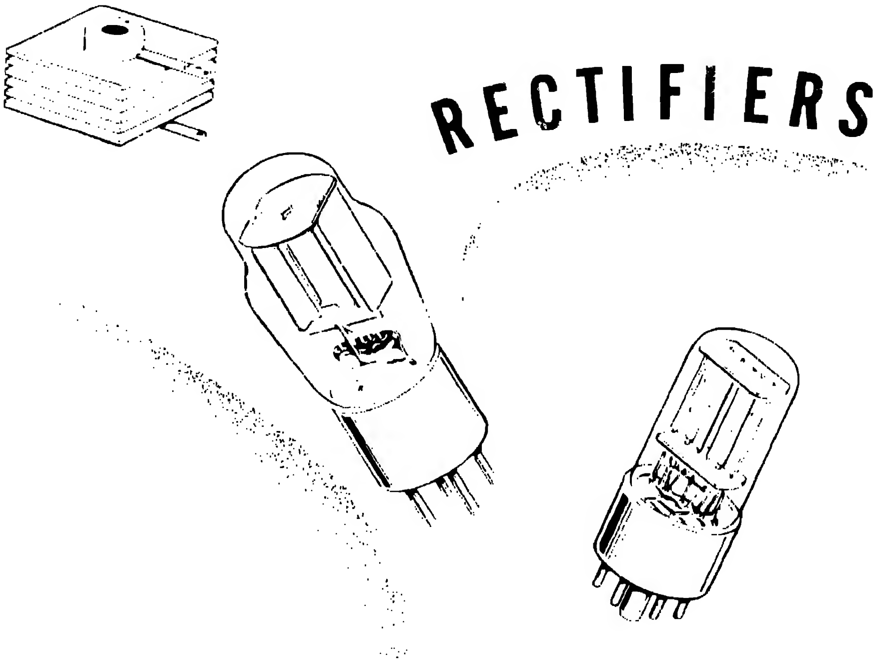
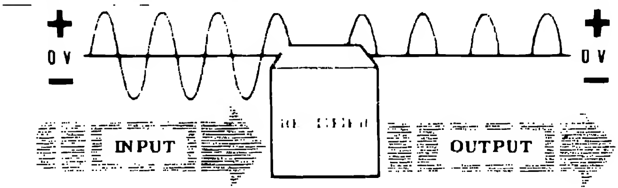
WHAT A POWER SUPPLY IS

How a Power Supply Works—The Rectifier (continued)

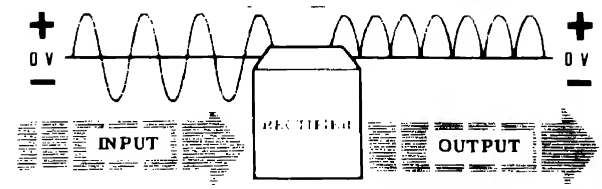
The rectifiers you will work with in this section will be dry metal or vacuum tube rectifiers. Either of these rectifiers come in half-wave or full-wave types. Vacuum tube rectifiers require that the transformer have a low voltage AC winding which supplies the rectifier tube with heater voltage. Dry metal rectifiers do not require this winding.



HALF-WAVE RECTIFICATION



FULL-WAVE RECTIFICATION

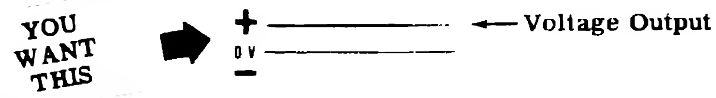


WHAT A POWER SUPPLY IS

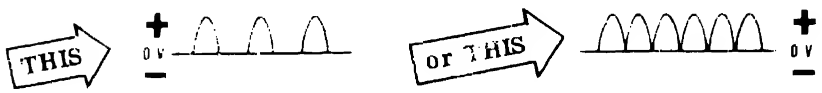
How a Power Supply Works—The Filter

So far you have learned that the job of a typical power supply is to take 117 volts AC from the power line and to deliver approximately 350 volts DC and 6.3 volts AC. You have learned that the major components of a power supply are a transformer, a rectifier and a filter circuit. You have learned the purpose of the transformer and the rectifier, and now you are ready to learn about the filter.

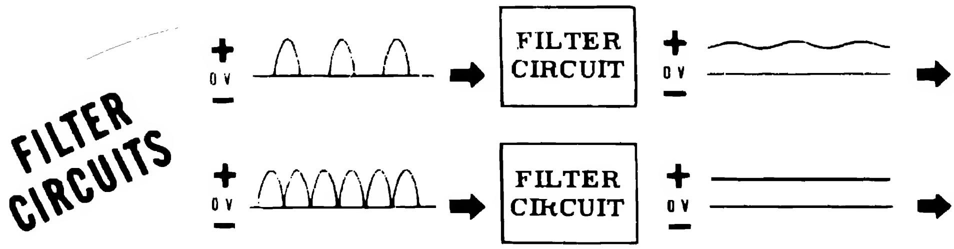
You know that the output of the rectifier is a pulsating DC voltage. What you want is a steady DC voltage of +350 volts with as little pulsation as possible.



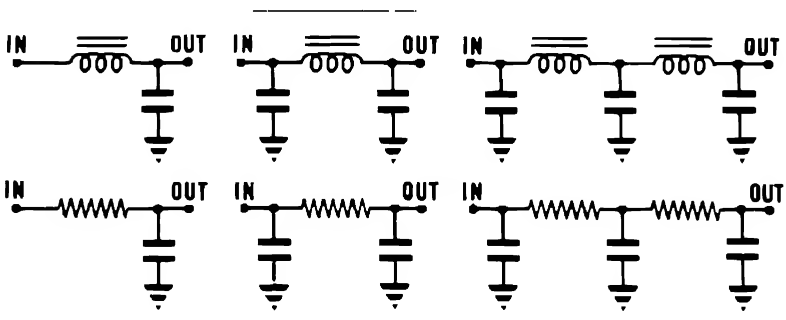
But the Rectifier gives you . . . .



The job of the filter circuit is to smooth out the pulsations in the rectifier output and give you a steady voltage with little or no ripple. Filter circuits come in various forms, but all filter circuits are made up of various combinations of inductances and capacitors or resistances and capacitors. You will learn how these filter circuits work to smooth out the pulsations in the rectifier output as soon as you have done some work with various rectifier circuits.



TYPICAL CIRCUITS



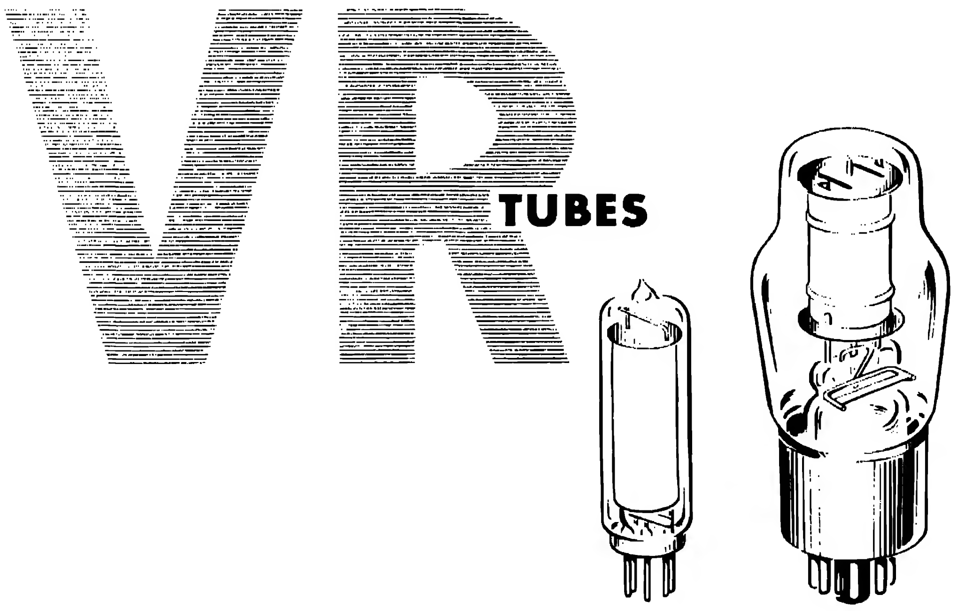
WHAT A POWER SUPPLY IS

Voltage Regulators

A typical power supply is made up of a transformer, a rectifier and a filter circuit. This is all that is required to give you the high voltage DC and the low voltage AC required to operate various types of electronic circuits. However, when current is drawn out of the high voltage DC terminal of a power supply, the voltage drops. This is due to the internal resistance of the power supply. It is not unusual for the 350-volt DC output to drop to 300 volts when the current drawn out increases from 0.05 amps to 0.100 amps.

This voltage drop is not serious for many types of electronic circuits, and they will go right on working in the proper manner. However, there are some types of electronic circuits that cannot operate properly if the voltage varies more than two or three volts. These types of circuits require that the power supply have a voltage regulator circuit added to it. When a power supply has a voltage regulator circuit, only those circuits that require a constant voltage are connected to the voltage regulator—other circuits are usually connected directly to the unregulated high voltage DC terminal.

The basic part of all voltage regulator circuits is the voltage regulator tube, commonly known as the "VR" tube. These tubes are made so that they will hold the DC voltage at a particular point in spite of current variations. VR tubes are made so that they will hold the voltage at 59, 75, 90, 108, and 153 volts DC. By using various combinations of these tubes, you can get a constant voltage of almost any value that is required.



WHAT A POWER SUPPLY IS

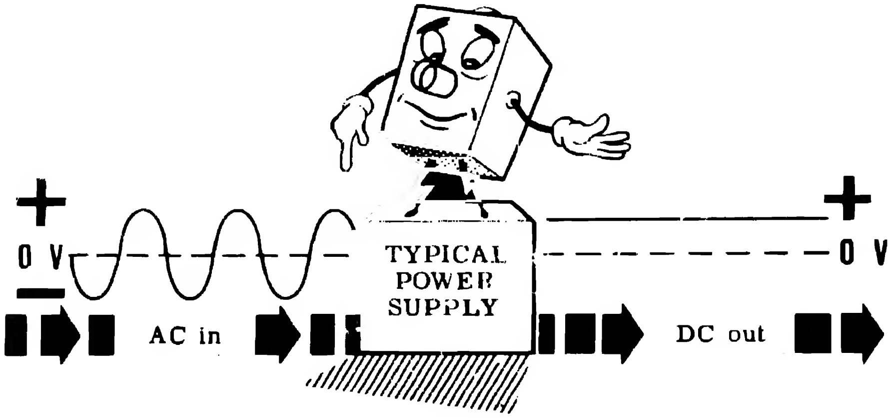
Why There are Different Types of Power Supplies

You know that most power supplies are made up of transformers, rectifiers, filter circuits and sometimes voltage regulators. You can get almost any kind of power supply you will ever see in the Navy by putting these components together in various ways. Of course, sometimes you will have to use large rectifier tubes and large transformers; sometimes you will have to use sub-miniature parts; but, large or small, all the circuits will contain the same components.

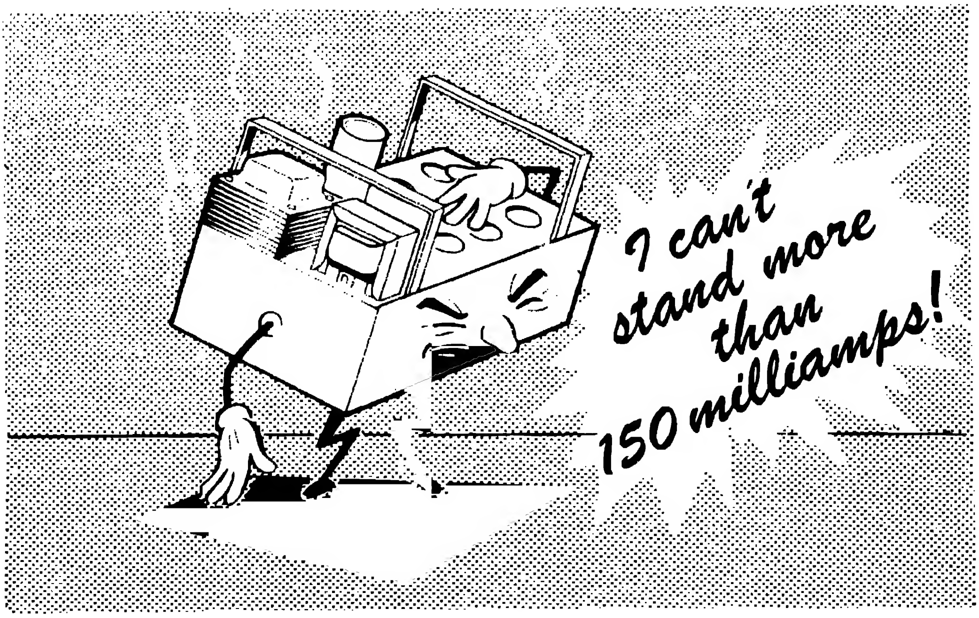
WHAT A POWER SUPPLY IS

Why There are Different Types of Power Supplies (continued)

Now you will want to know why there are different types of power supplies used in various types of equipment. After all, the major job they do is nothing more than changing AC into DC.



The reason why different types of power supplies are required is simple. The power supply you will build would go up in smoke if you drew much more than 150 ma. of current from the high DC voltage supply. Certain types of Navy transmitters require as much as 5,000 or 10,000 ma. from their power supplies. This is many times more than your power supply will furnish. Certain special Navy oscilloscope circuits may require a DC output of 10,000 volts or more. This is well over 20 times the voltage your power supply will be able to furnish.



WHAT A POWER SUPPLY IS

Why There are Different Types of Power Supplies (continued)

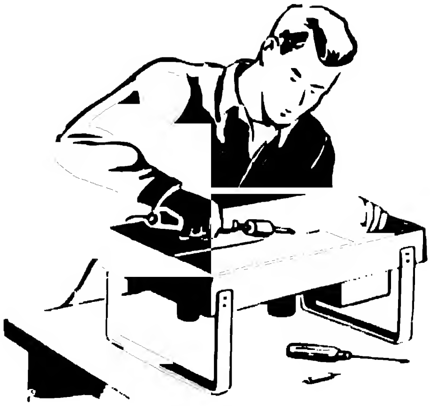
Some special Navy radar circuits require power supplies with especially good voltage regulation. This means that the DC voltage put out by the power supply must not change more than one or two volts when the current is varying.

Sometimes power supplies are needed that will put out negative DC voltages rather than positive DC voltages. Sometimes power supplies are needed that will put out several positive and several negative DC voltages. Sometimes a super-low ripple is required, etc. etc.

From this, you can see that the Navy has many jobs for power supplies for which your typical power supply could not qualify.

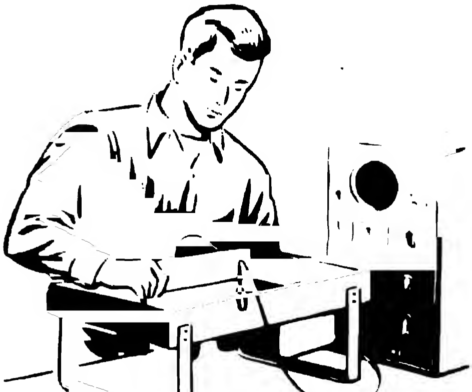
WHAT A POWER SUPPLY IS

How You Will Learn about Power Supplies



You will learn all you need to know about Power Supplies in the same manner that you learned Basic Electricity—by reading, discussing, building, observing demonstrations and performing experiments. Once you get well started in this work you are also going to learn by troubleshooting. By learning to locate troubles in defective power supplies and by making the required repairs, you will gain much experience that will be of benefit to you in the Fleet.

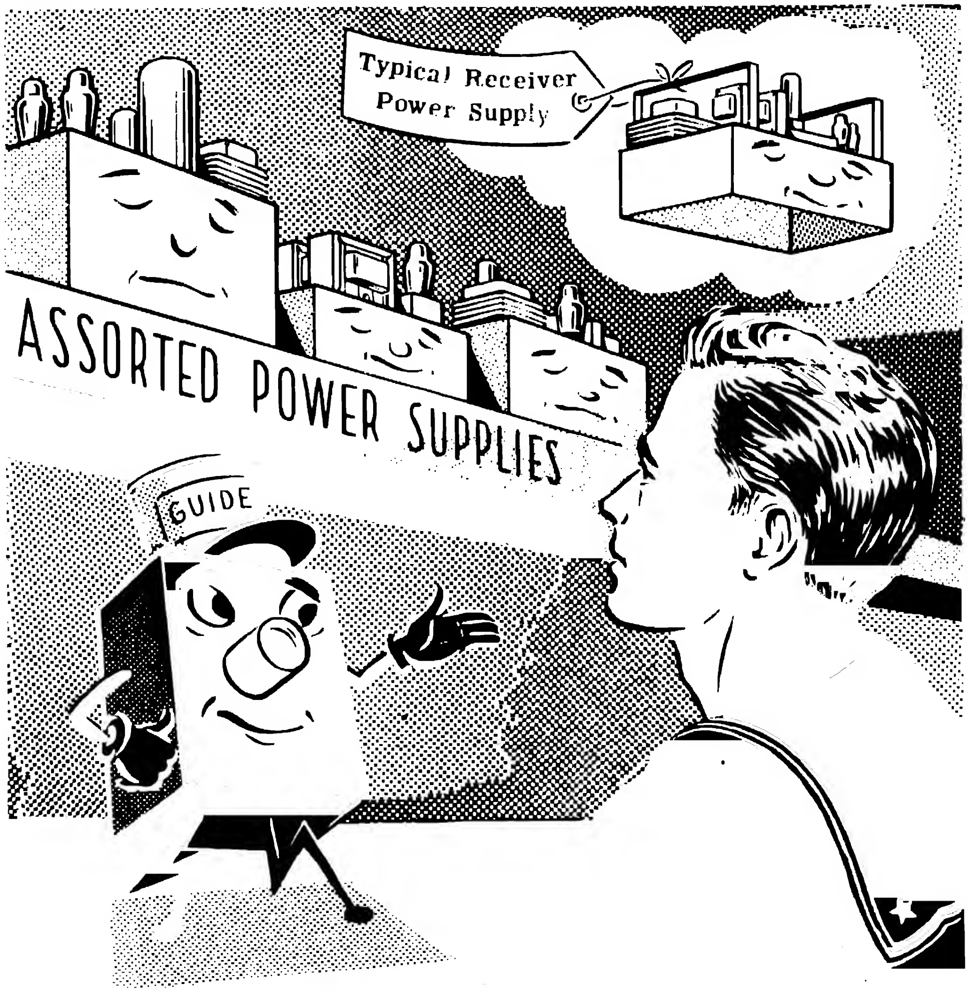
Troubleshooting practice will make you skilled in the use of such test equipment as meters and the oscilloscope. When you have become a successful troubleshooter of power supplies, you know that you have accomplished a big step towards becoming a successful operator or technician.



How You Will Learn about Power Supplies (continued)

Many types of electronic equipment require several different DC voltages for proper operation. If the equipment contains a 'scope tube, it will need a DC voltage of several thousand volts. In addition, it will need a few hundred volts DC to operate the vacuum tubes in the set as well as a low AC voltage of 6.3 volts for the heaters of the tubes. The power supply takes the line voltage which is usually 117 volts AC and converts it to the required large DC voltages and to the low AC voltages.

You are going to build several power supply circuits and you'll wind up with a fairly typical power supply. Later on, you will use this power supply in connection with the many circuits you will build and study in this phase of your training. Although this power supply is typical, it is by no means the only power supply you will find in Navy equipment. You are going to learn enough about many types of power supplies so that you'll be able to understand any of them that you might find when you're out in the Fleet.



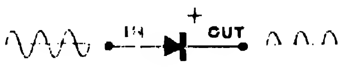
WHAT A POWER SUPPLY IS

How You Will Learn about Power Supplies (continued)

You know that power supplies are made up of various combinations of transformers, rectifiers, filter circuits and sometimes voltage regulators. You will learn about power supplies by working with these circuits individually and by putting them together to make up a complete typical power supply.

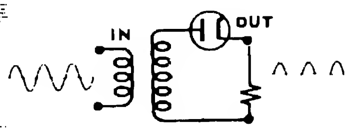
Here is an outline of the work that is cut out for you in this section:

A. Half-Wave Rectifier—Dry Metal Type

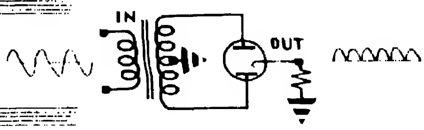


B. Half-Wave Rectifiers—Vacuum Tube Type

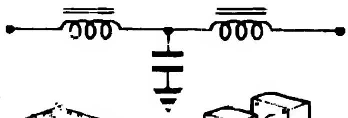
C. Half-Wave Rectifiers—Transformer Type



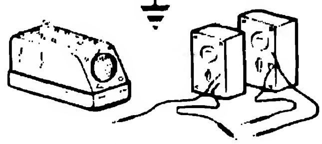
D. The Full-Wave Rectifier



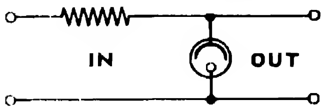
E. Filter Circuits



F. Troubleshooting Power Supplies



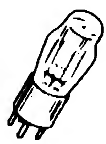
G. Voltage Regulator Circuits



H. Miscellaneous Power Supplies

vibrators
dynamotors
etc.

I. The Diode Tube

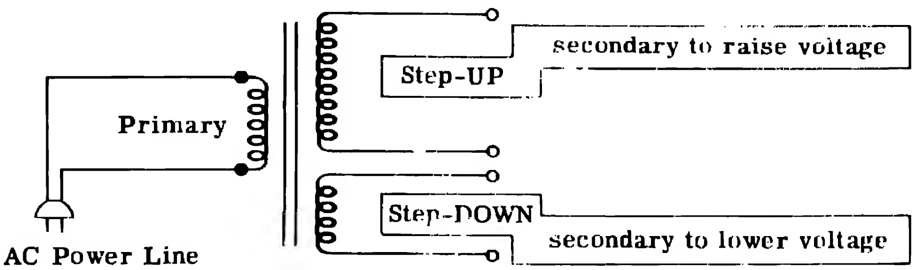


HALF-WAVE RECTIFIERS—DRY METAL TYPE

Changing AC to DC

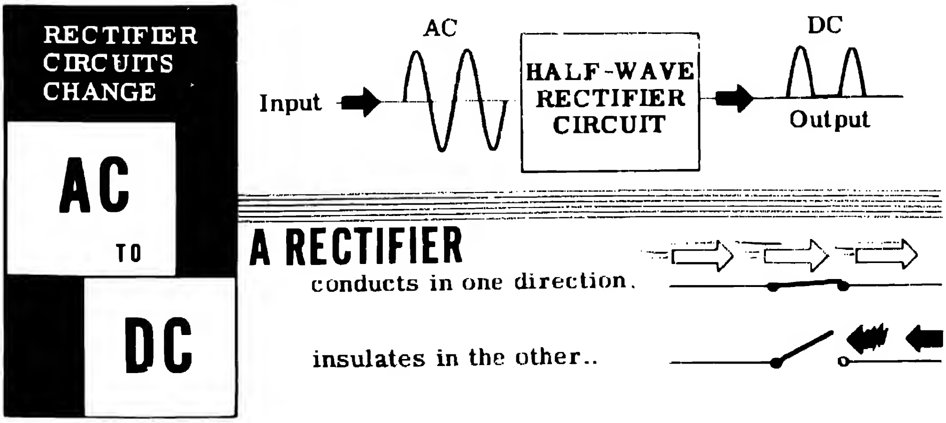
Most electric power is distributed by AC power lines and most electronic equipments contain power supplies which change the AC power line voltage to those DC and AC voltages required by the equipment. To change the AC power line voltage to other AC voltages is relatively simple. A transformer is used to either step up or step down the line voltage, to obtain the required AC voltages.

POWER SUPPLY TRANSFORMERS STEP UP OR STEP DOWN VOLTAGES AS REQUIRED



To obtain the required DC voltages, the AC line voltage must be changed to DC. This changing of AC to DC is called "rectification." Devices which change AC to DC are called "rectifiers" and circuits used to change AC to DC are called "rectifier circuits."

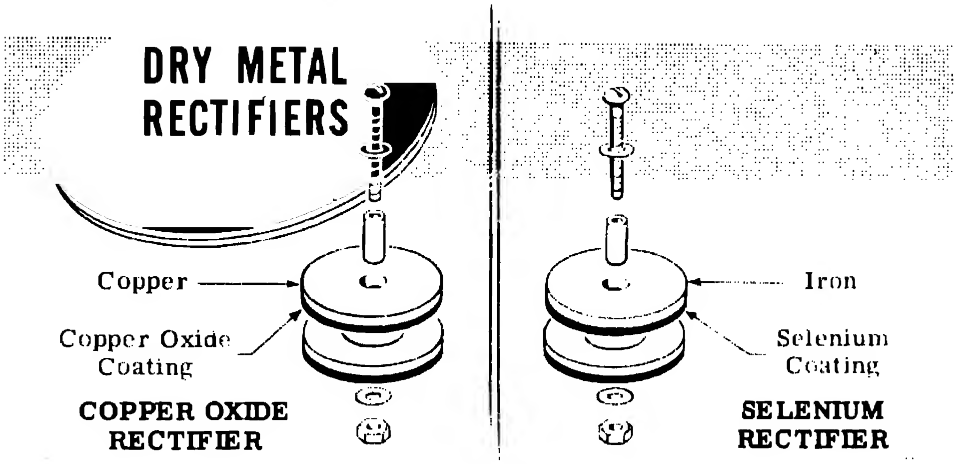
Rectifiers are devices which allow current to flow through them in one direction only, acting as a conductor for current flow in one direction and as an insulator for current flow in the other direction. Thus when a rectifier is placed in an AC circuit every other half-cycle of the AC voltage causes current flow in the circuit in that direction for which the rectifier is a conductor. Since the alternate half-cycles are trying to force current through the circuit in a direction for which the rectifier acts as an insulator, no current flows during these alternate half-cycles. As a result, the current flow in a simple rectifier circuit is pulsating DC (alternate half-cycles of AC) rather than a steady DC current flow.



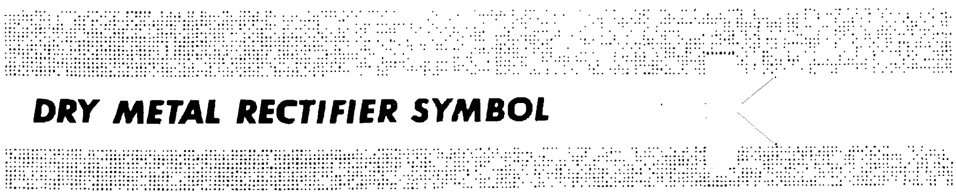
HALF-WAVE RECTIFIERS—DRY METAL TYPE

Dry Metal Rectifiers

When certain metallic materials are pressed together to form a junction, the combination acts as a rectifier having a low resistance to current flow in one direction and a very high resistance to current flow in the opposite direction. This action is due to the chemical properties of the combined materials. The combinations usually used as rectifiers are copper and copper-oxide, or iron and selenium. Dry metal rectifiers are constructed of disks ranging in size from less than a half inch to more than six inches in diameter. Copper-oxide rectifiers consist of disks of copper coated on one side with a layer of copper oxide while selenium rectifiers are constructed of iron disks coated on one side with selenium.



Dry metal rectifier elements (an element is a single disk) are generally made in the form of washers which are assembled on a mounting bolt in any desired series or parallel combination to form a rectifier unit. The symbol shown below is used to represent a dry metal rectifier of any type. Since these rectifiers were made before the electron theory was used to determine the direction of current flow, the arrow points in the direction of conventional current flow but in the direction opposite to the electron flow. Thus the arrow points in opposite direction to that of the current flow as used in electronics.

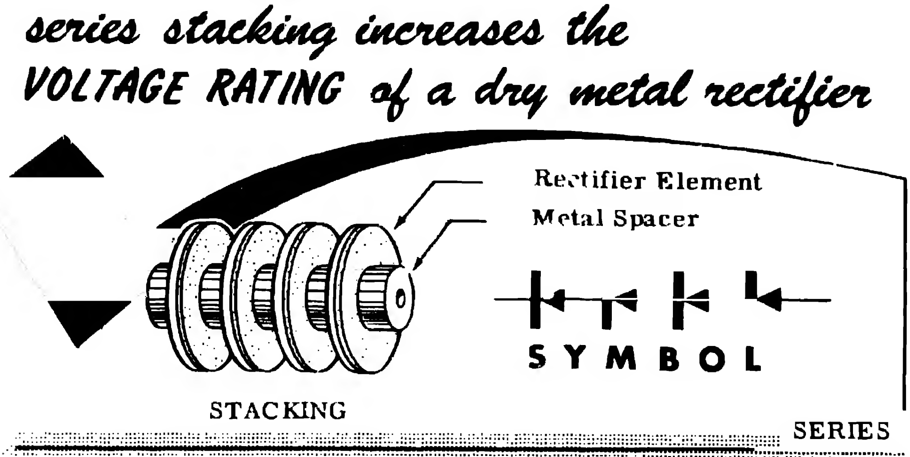


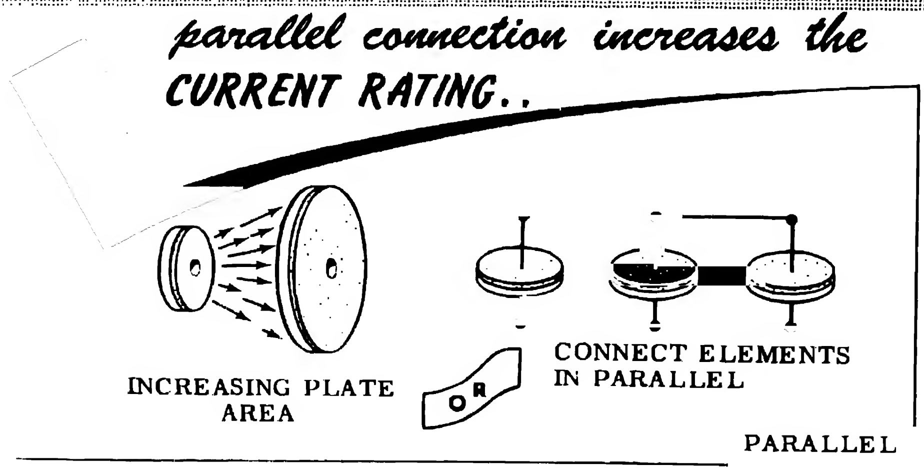
ELECTRON current flow
opposite direction from symbol arrow

HALF-WAVE RECTIFIERS—DRY METAL TYPE

Dry Metal Rectifiers (continued)

Each dry metal rectifier element will stand only a few volts across its terminals but by stacking several elements in series the voltage rating is increased. Similarly each element can pass only a limited amount of current. When greater current is desired several series stacks are connected in parallel to provide the desired amount of current.

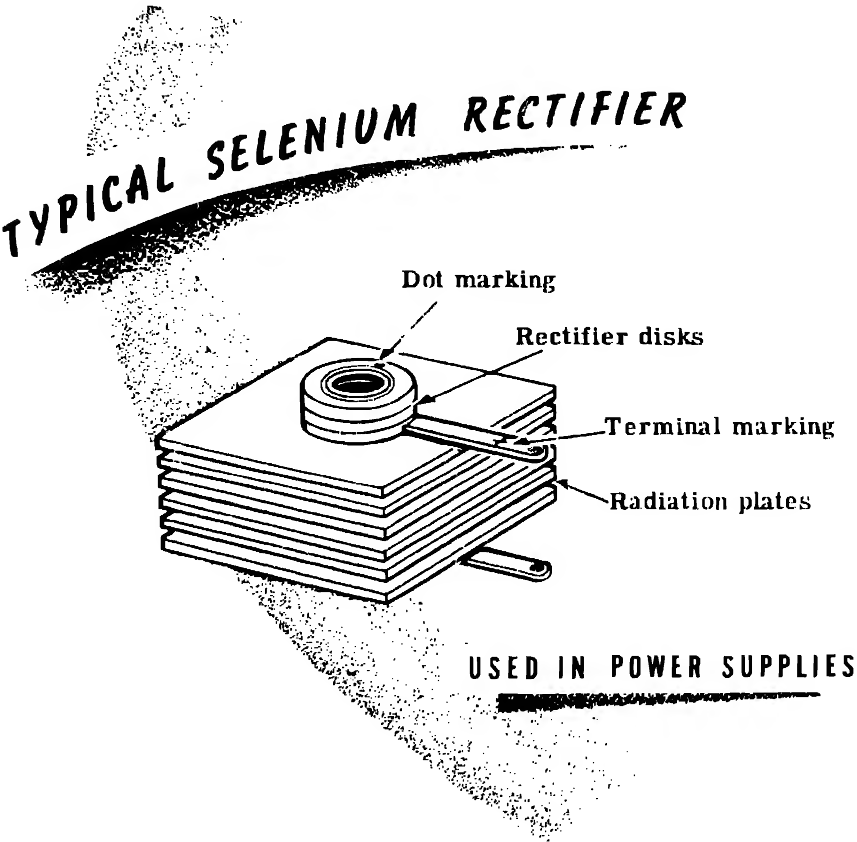




Dry metal rectifiers are very rugged and have an almost unlimited life if not abused. Because of the low voltage rating of individual units they are normally used for low voltages (130 volts or less) since it becomes impractical to connect too many elements in series. By paralleling stacks or increasing the diameter of the disks, the current rating can be increased to several amperes so that they are often used for low voltage-high current applications. Very small units are used to measure AC voltage on a DC voltmeter. Larger units are used in battery chargers and various types of power supplies for electronic equipment.

Dry Metal Rectifiers (continued)

Selenium rectifiers are used in power supplies while copper oxide rectifiers are used in special applications such as meter rectifiers. A typical selenium rectifier of the type used in practical power supplies is illustrated below. It is rated at 130 volts AC and can furnish a maximum of 100 ma. of DC current. The + terminal marking indicates the polarity of the rectifier and is used for identification of leads when connecting the rectifier in a circuit. The positive terminal is sometimes identified by a red dot and the negative terminal by a yellow dot.



A perfect rectifier would offer no resistance to current flow in one direction and infinite resistance in the opposite direction, but such a rectifier is only theoretical. Practical rectifiers used in power supplies actually have low resistance in one direction and very high resistance in the opposite direction. For dry metal rectifiers these resistances can be measured with an ohmmeter.

To test a selenium rectifier the resistance across the terminals is measured in one direction, and then the ohmmeter leads are reversed to measure the resistance in the opposite direction. If the high reading is 10 or more times as large as the low reading, the rectifier is in good condition.

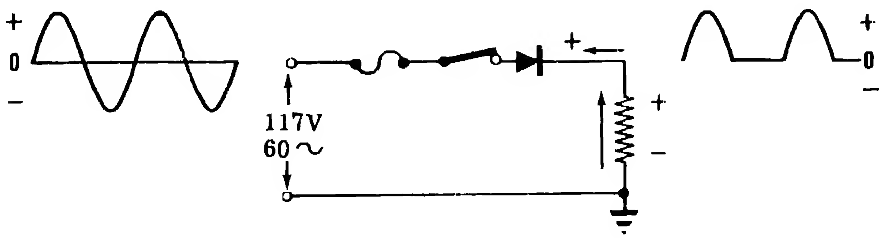
HALF-WAVE RECTIFIERS—DRY METAL TYPE

A Half-Wave Rectifier Circuit

A basic half-wave rectifier circuit consists of a rectifier connected in series between the AC voltage source and the circuit load resistance. The rectifier permits current to flow only during the positive half cycles of the applied AC voltage and the circuit current then is pulsating DC. In the circuit illustrated, the applied line voltage is 117 volts, 60 cycles AC and current flows only for one half of each cycle. Thus the current flow through the circuit is in pulses at the rate of 60 pulses per second. Actually there is a slight current flow in the opposite direction during the negative half cycles but it is so small that it is considered to be zero.

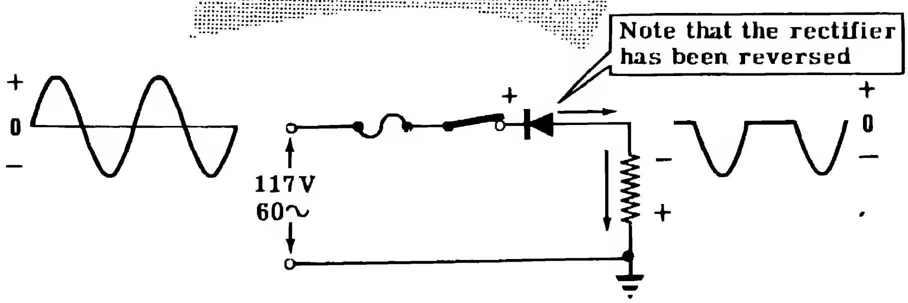
This simple circuit illustrated is the basic circuit used to change AC to DC. When connected as shown, the DC voltage across the load resistor is positive at the end which connects to the rectifier and negative at the other end. The negative terminal of the load resistor is normally grounded to the chassis in a power supply.

HALF-WAVE RECTIFIER CIRCUIT



To reverse the polarity of the DC voltage obtained, the rectifier is reversed. This allows current to flow only on the opposite half cycles as compared to the previous circuit. This circuit is used to obtain a negative DC voltage with respect to ground. The grounded end of the load resistor is positive.

REVERSING THE POLARITY OF OUTPUT VOLTAGE

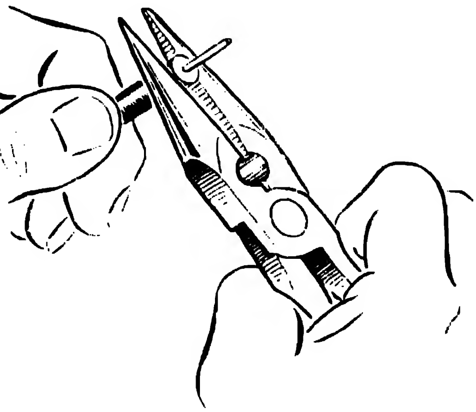


HALF-WAVE RECTIFIERS—DRY METAL TYPE

Review of Soldering Methods

It is important that you fully understand all the techniques of soldering. If good circuit connections are not made, they may very well affect the operation of your vacuum tube.

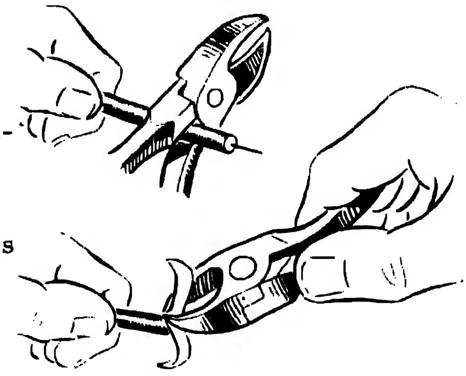
1. Plug in the soldering iron. You already know how to use it; but remember, as soon as it gets hot, to wipe the tip with steel wool or a rag. The tip should be clean and tinned. If it is not clean and tinned, touch a piece of solder to it at several places, spread the melted solder with the steel wool or rag and wipe it off. Remember to leave a small amount of solder on the tip in order to conduct heat to the part being soldered.



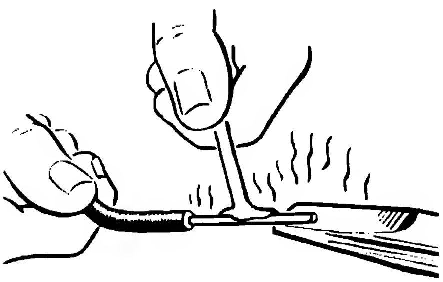
Baring the end of push-back wire

2. In order to solder a wire to terminal or a tube socket soldering lug:

   a. Bare about 3/8 inch of the end of the wire by pushing back the insulation if you have push-back wire, or by crushing the insulation with the pliers and cutting off the insulation for most other types of wire. This is how it is done:



Baring the end of other type wire



Tinning a wire

   b. If the wire is not the pre-tinned type, scrape the bared end with a knife until bright copper shows and tin, as shown here:

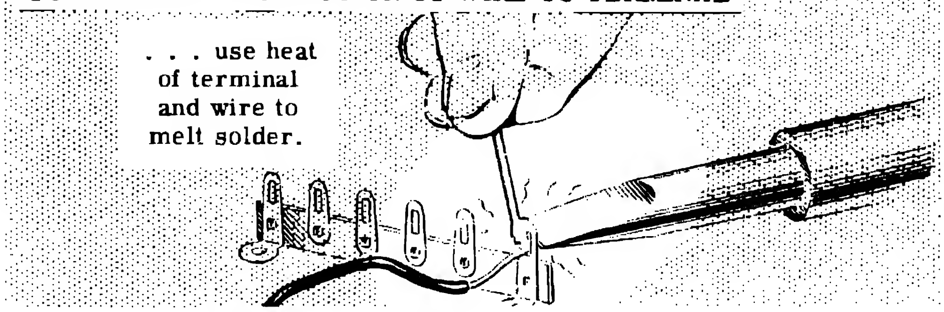
   Heat the wire with the soldering iron. Touch the solder to the wire—not to the iron, otherwise the solder may not cover the bare end properly. Rub the solder over the bared end. Wipe clean with paper or a rag.

Review of Soldering Methods (continued)

c. Make a good mechanical connection between the bared end and the terminal. Do not wrap the wire more than once around the terminal because it may have to be removed for test purposes.

d. Heat the terminal with the soldering iron. Touch solder to the wire and terminal until the connection is covered with melted solder. Remove the solder. Keep applying heat for one second and remove the iron. Allow the solder to harden and wipe off any excess flux with a rag to make a neat, clean connection.

TO SOLDER A CONNECTION OF WIRE TO TERMINAL



3. Remember that in order to solder anything to the chassis, both surfaces to be joined must be tinned and clean. Follow these steps:

a. Scrape the desired spot clean with any sharp tool.

b. Get the spot well heated with the soldering iron.

c. Still applying heat to the chassis, touch the solder to the cleaned spot—not to the iron.

d. When a bit of solder melts and sticks to the chassis, spread the pool of melted solder with the tip of the iron until you have a thin layer over the cleaned spot. Wipe clean with a rag or paper.

e. Press the part which you wish to connect to the chassis firmly against the layer of solder and hold it steady with the pliers. If the part is not pre-tinned, follow the same procedure as for tinning the chassis.

f. Heat the part to be mounted until the layer of solder on the chassis melts and sticks to the part.

g. Apply a little more solder until there is a tiny pool of melted solder covering the part to be mounted. Remove the heat.

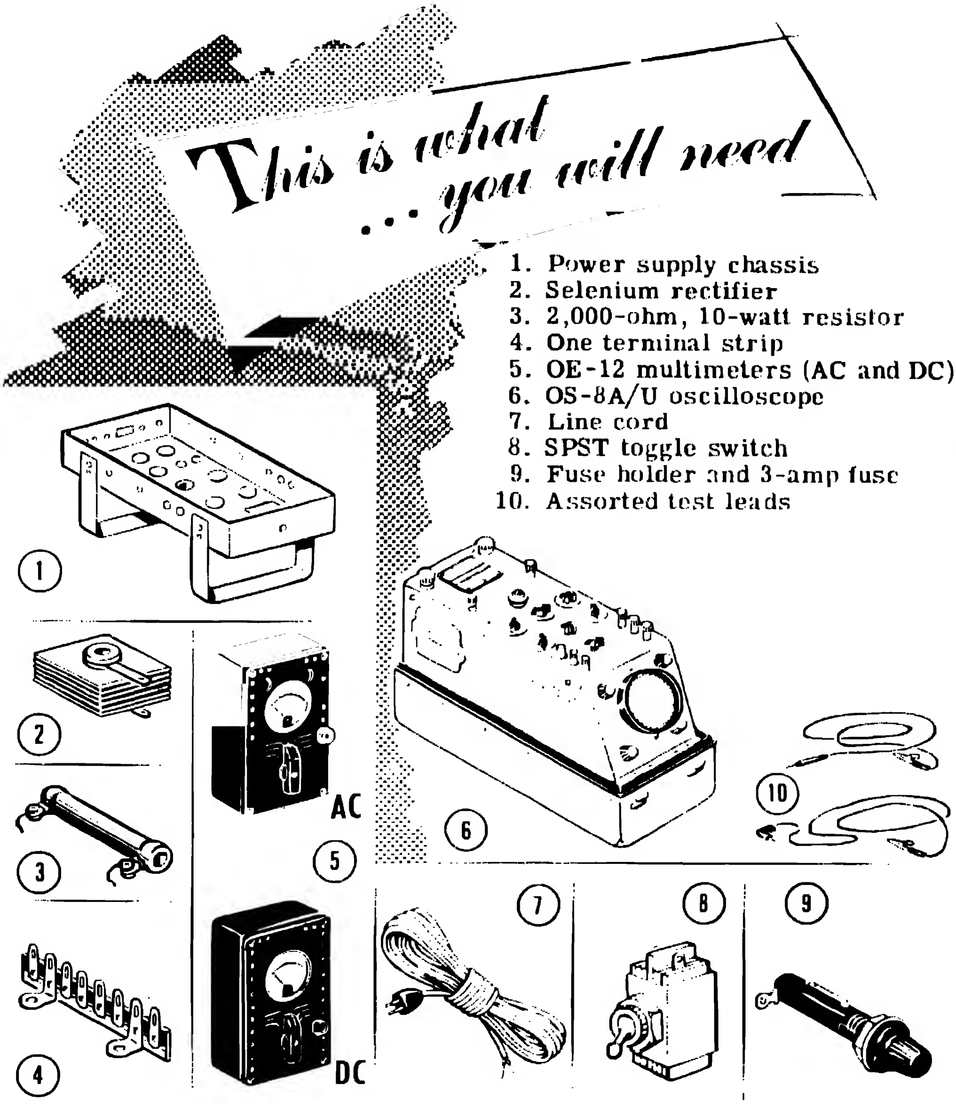
h. Hold the part steady with the pliers until the solder has hardened. Wipe clean with a rag or paper.

HALF-WAVE RECTIFIERS—DRY METAL TYPE

Experiment on a Half-Wave Rectifier Circuit

The purpose of this experiment is to show how AC can be changed to DC by using a selenium rectifier. In addition you will learn how to mount and wire parts on a chassis, how to measure the AC and DC voltages in the circuit and how to use the 'scope to observe circuit waveforms. You will use resistance, voltage and waveform analysis to check parts, circuit wiring and circuit operation. The same basic procedures are used to troubleshoot circuits of all types.

Tools, hookup wire and miscellaneous hardware are needed for each experiment and are not included in lists of parts required for the experiments.



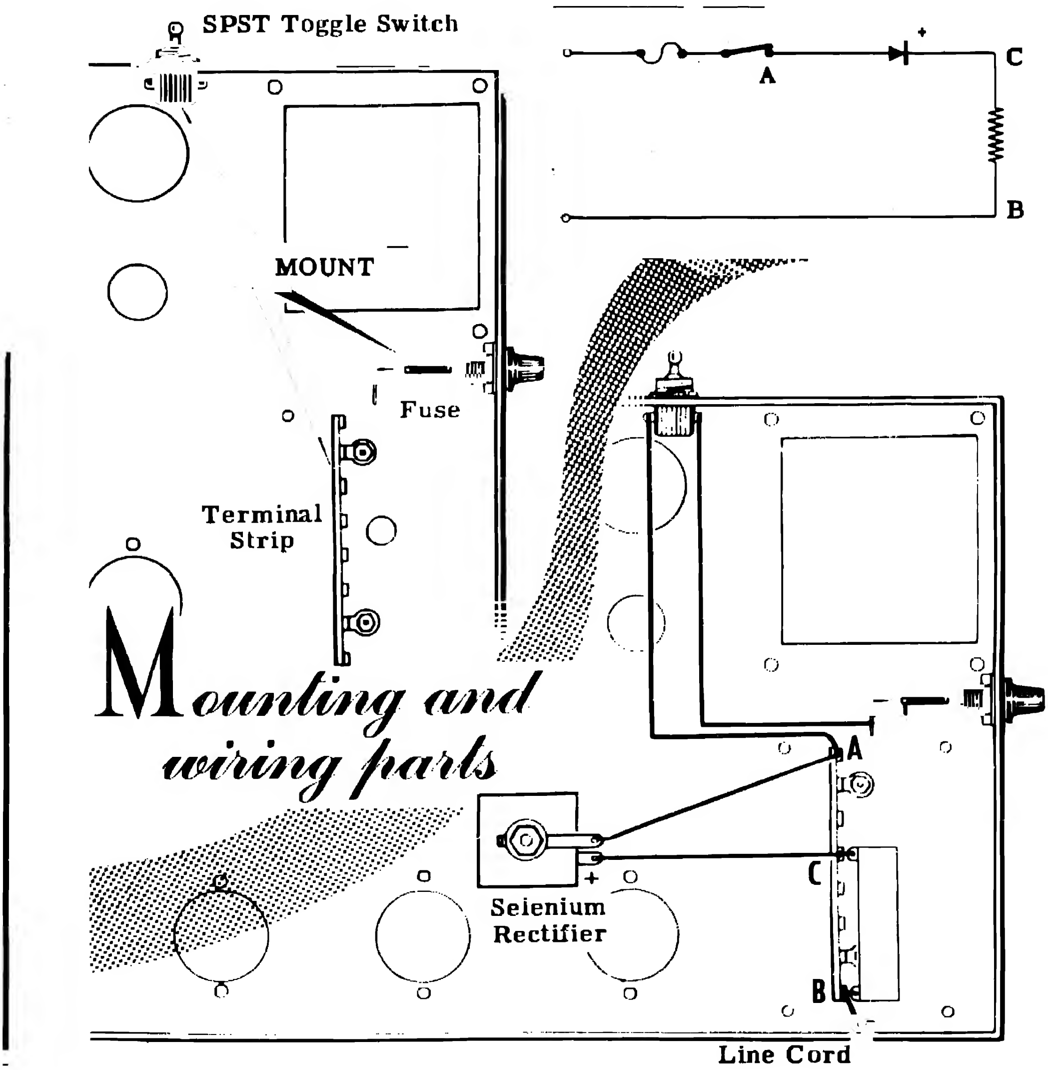
1. Power supply chassis
2. Selenium rectifier
3. 2,000-ohm, 10-watt resistor
4. One terminal strip
5. OE-12 multimeters (AC and DC)
6. OS-8A/U oscilloscope
7. Line cord
8. SPST toggle switch
9. Fuse holder and 3-amp fuse
10. Assorted test leads

HALF-WAVE RECTIFIERS—DRY METAL TYPE

Experiment—Mounting and Wiring the Parts of a Half-Wave Rectifier

To demonstrate the correct methods of mounting and wiring parts of a chassis, the instructor constructs the half-wave rectifier circuit. The fuse, selenium rectifier, terminal strip and switch are mounted on the chassis, then the 2,000-ohm resistor is soldered in place on the terminal strip. After the parts are mounted the circuit is wired as illustrated. The selenium rectifier is first connected to the terminal strip, then the switch and the line cord are wired to complete the circuit.

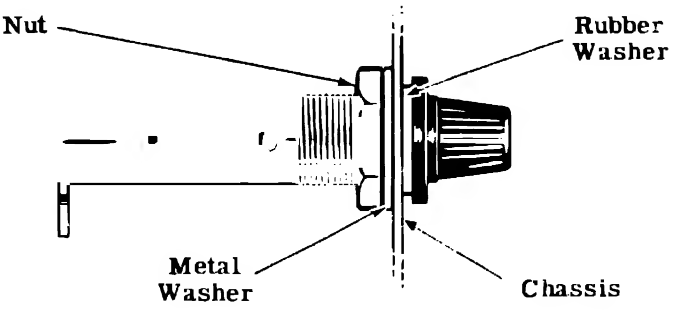
When the mounting and wiring are completed you see that the parts and wiring closely resemble the circuit diagram. The wiring is checked by starting at one side of the circuit and tracing through the circuit diagram and the wiring at the same time.



HALF-WAVE RECTIFIERS—DRY METAL TYPE

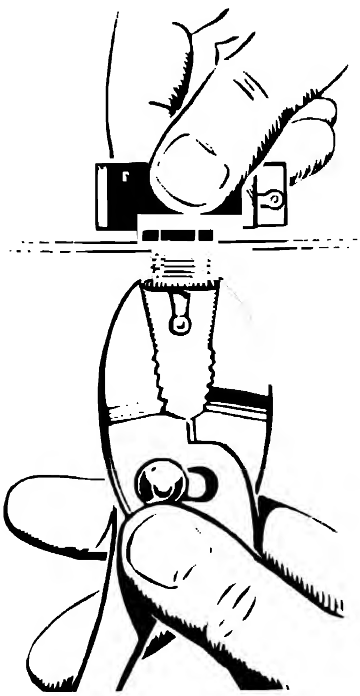
Experiment—Building the Half-Wave Rectifier Circuit

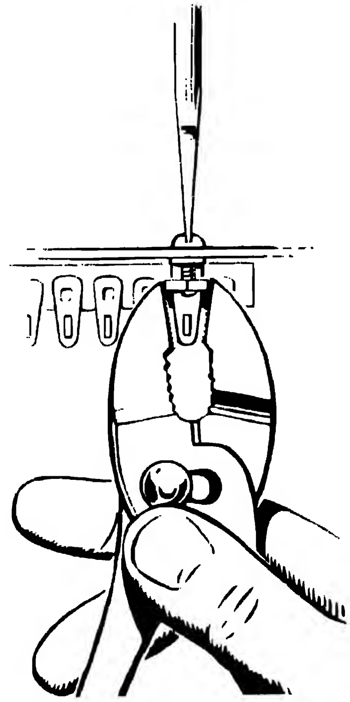
1. Mount the fuse on the chassis, leaving the rubber washer next to the bakelite shoulder to prevent it from cracking when the nut is tightened.



2. Remove the special nut from the SPST toggle switch and place the switch in the mounting hole. Hold the switch and tighten the nut with a pair of pliers as shown here.

3. Locate the terminal strip position from the circuit diagram and mount the terminal strip with a screwdriver while holding the nut with pliers.

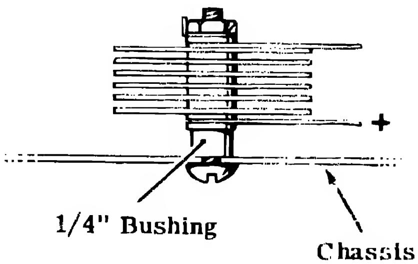


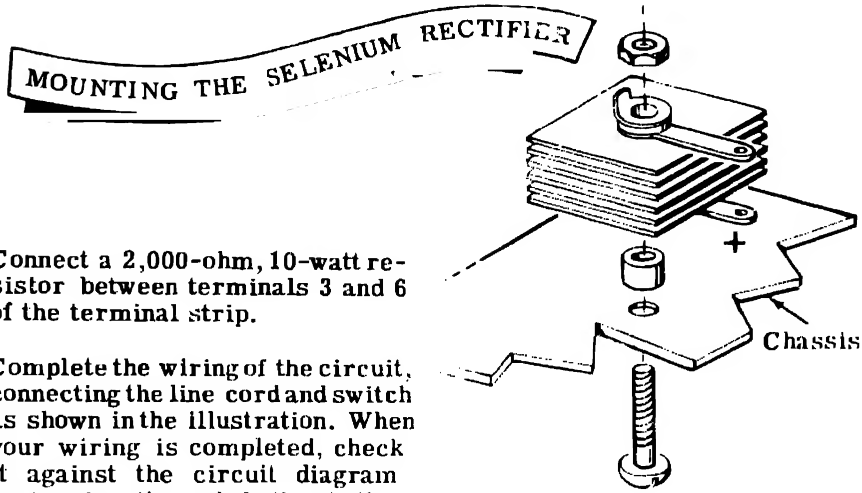


HALF-WAVE RECTIFIERS—DRY METAL TYPE

Experiment—Building the Half-Wave Rectifier Circuit (continued)

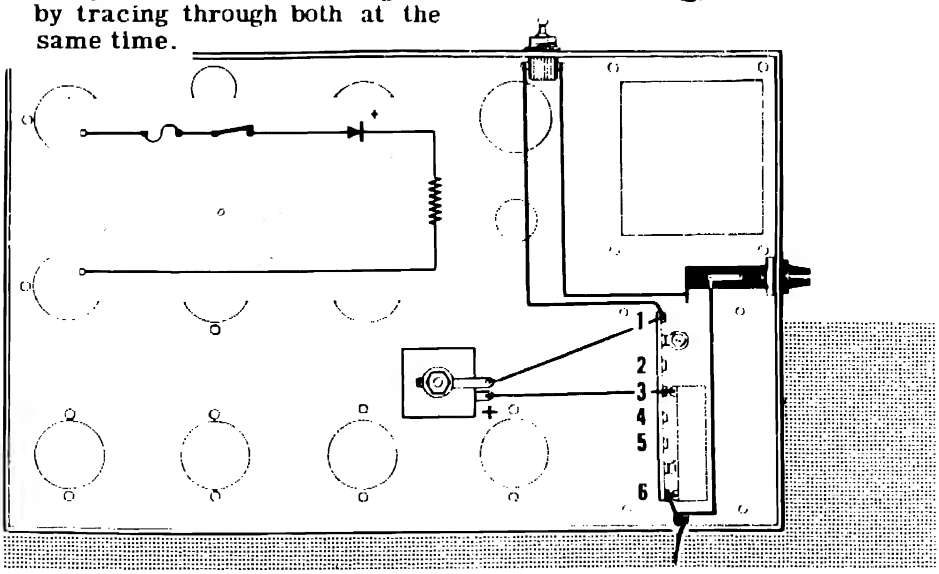
4. Mount the selenium rectifier as illustrated. Connect the rectifier between terminals 1 and 3 of the terminal strip. The + lead of the rectifier connects to terminal 3 and the other lead connects to terminal 1.





5. Connect a 2,000-ohm, 10-watt resistor between terminals 3 and 6 of the terminal strip.

6. Complete the wiring of the circuit, connecting the line cord and switch as shown in the illustration. When your wiring is completed, check it against the circuit diagram by tracing through both at the same time.

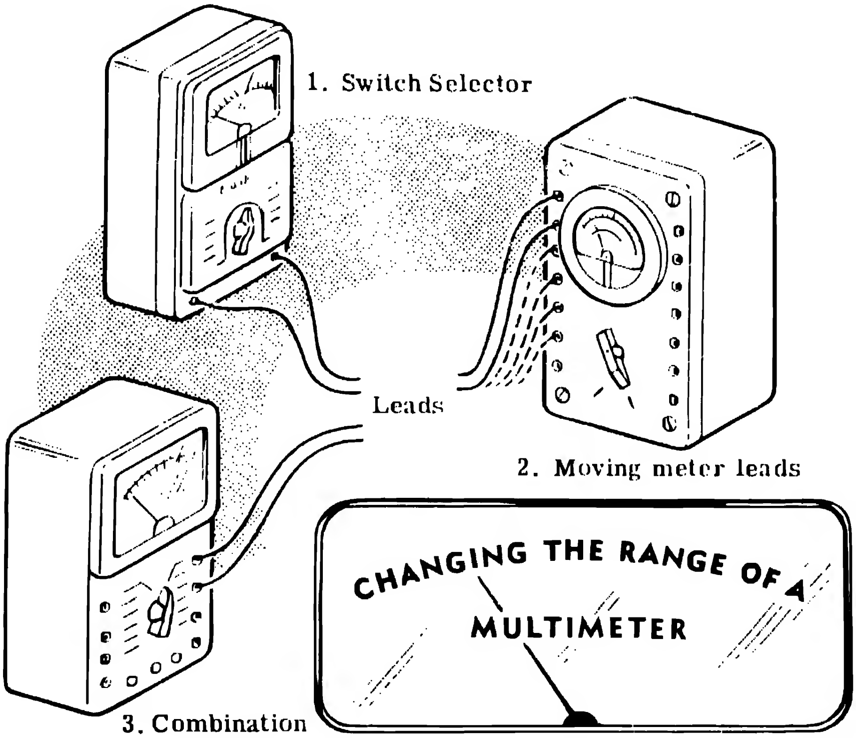


HALF-WAVE RECTIFIERS—DRY METAL TYPE

Multimeters

To test electronic circuits (for example a rectifier circuit), resistances, AC and DC voltages and currents are measured. Because the values of resistance, voltage and current to be measured differ greatly, several ohmmeter, voltmeter and milliammeter ranges are required. A multimeter is a combination volt-ohmmeter-milliammeter having various ranges for measuring voltages, resistances and current. The multimeter has a single meter movement, with various shunt and multiplier combinations used to obtain different meter ranges.

Multimeter ranges are selected in three ways (1) by means of a switch (2) by changing meter lead connections from one set of pin jacks to another (3) by a combination of switching and moving meter leads to various pin jacks or meter terminals.



By using these methods of changing its range, a single basic meter movement may be used as an ohmmeter, voltmeter or milliammeter. (Currents to be measured in electronic circuits usually are in milliamperes.)

When used as a voltmeter the switch connects the basic meter movement in series with a multiplier resistor which determines the voltage range for DC volts. A rectifier is also switched into the meter circuit on the AC voltage ranges. When used as a milliammeter the switch connects a shunt across the meter movement to increase its range. For the ohmmeter ranges a battery and a zero-set potentiometer are connected to form a resistance-measuring circuit of the desired range.

HALF-WAVE RECTIFIERS—DRY METAL TYPE

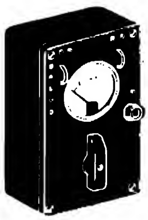
Demonstration—Multimeters and Methods of Circuit Analysis

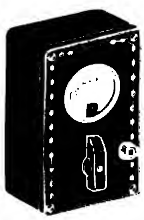
The purpose of this demonstration is to acquaint you with multimeters and methods of circuit analysis. In order to observe a circuit in operation and in order to troubleshoot it, you must use various instruments and procedures. In your Basic Electricity course you made use of separate voltmeters, ammeters and ohmmeters in checking circuit operation. It is not practical for you to carry around six or eight meters while you are doing your work aboard ship, and it is for this reason that multimeters (multipurpose meters) are used. Two multimeters—the OE-12 AC and DC meters—pretty much satisfy all the meter requirements you will require in your routine duties. The instructor will demonstrate how these meters are used.

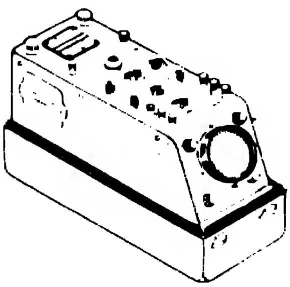
There are standard methods of checking the operation of electronic circuits—resistance measurements, voltage measurements and wave form analysis. The instructor will demonstrate these methods and explain their advantages and disadvantages.

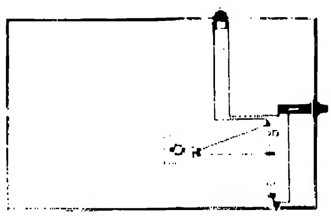
This Is What Is Needed

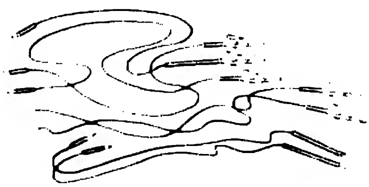
1. An OE-12 DC multimeter
2. An OE-12 AC multimeter
3. An OS-8A/U oscilloscope
4. A chassis with dry metal rectifier circuit
5. Assorted test leads









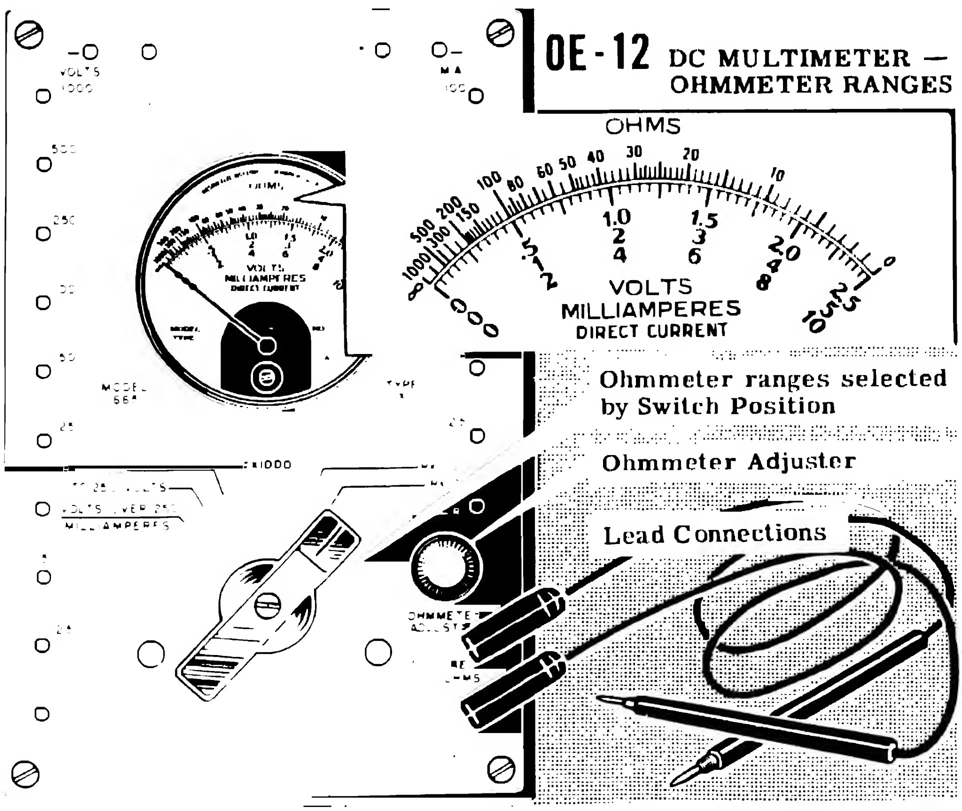


HALF-WAVE RECTIFIERS—DRY METAL TYPE

Demonstration—OE-12 DC Multimeter

The instructor will demonstrate the operation and use of the OE-12 DC multimeter, a combination DC voltmeter, DC milliammeter and ohmmeter which you will use to test various circuits. This multimeter has five resistance ranges, ten DC voltage ranges and seven DC current ranges. The meter scale is calibrated for all of these ranges.

The instructor will first show how this multimeter is used as an ohmmeter. The basic ohmmeter range is position R on the selector switch. With the switch turned to this position and meter leads inserted in the pin jacks marked RES OHMS, the meter is connected for use as an ohmmeter having a range of 0-1000 ohms. The ohms scale is the top scale of the meter dial. Whenever the meter is used as an ohmmeter, it must first be "zeroed." To "zero" the meter the test prods are shorted together and the OHMMETER ADJUSTER knob is turned to place the meter pointer at zero on the ohmmeter scale. After zeroing, the meter may be used to measure resistance by putting the test prods across the terminals of the resistance to be measured. The resistance value indicated on the ohmmeter scale is read directly for ohmmeter range R. To increase the ohmmeter range the selector switch is turned to R x 10, R x 100, R x 1000, or R x 10,000 depending on the range required. The resistance value indicated by the meter scale is then multiplied by the amount indicated by the selector switch pointer. Whenever the ohmmeter range is changed, the zero position should be checked.

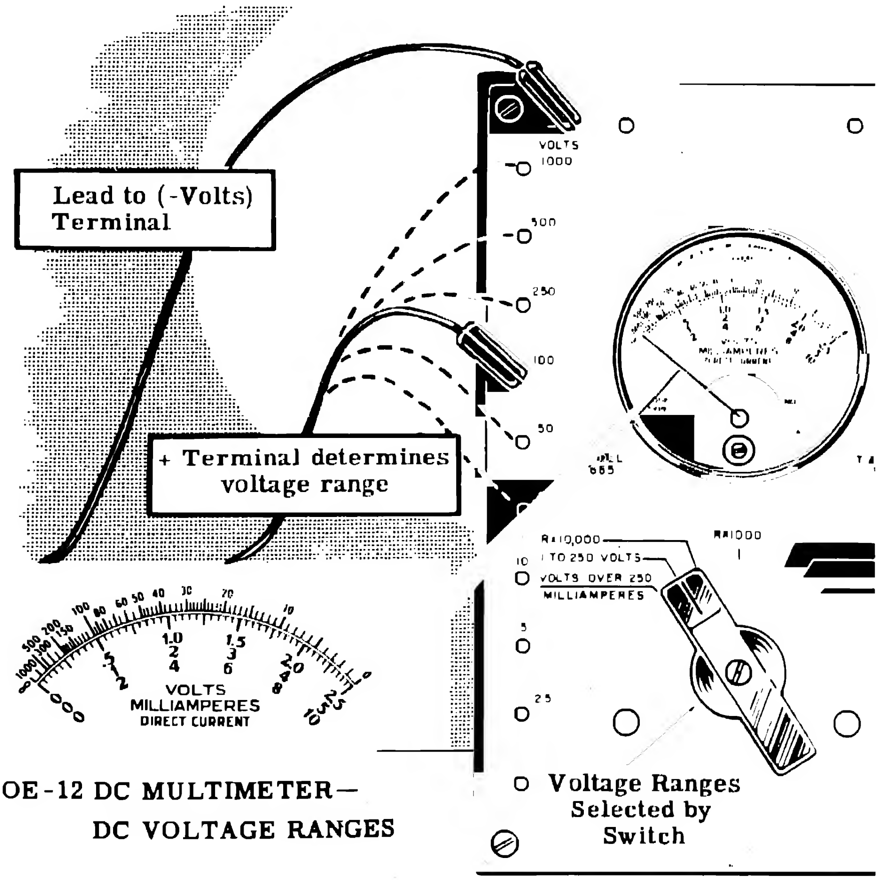


HALF-WAVE RECTIFIERS—DRY METAL TYPE

Demonstration—OE-12 DC Multimeter (continued)

In this part of the demonstration, the instructor will show how to use this multimeter as a DC voltmeter. To use the OE-12 DC multimeter as a DC voltmeter, the selector switch is turned to the position marked 1 TO 250 VOLTS for DC voltage ranges not greater than 250 volts and to the position marked VOLTS OVER 250 for the higher DC voltage ranges. For all voltage ranges the NEGATIVE meter lead is connected to the pin jack marked (—) at the top left corner of the meter case. One jack in the row of pin jacks marked VOLTS on the left side of the case is selected by connecting the POSITIVE meter lead to the pin jack marked with the desired range. The selector switch must also be set to cover this voltage range.

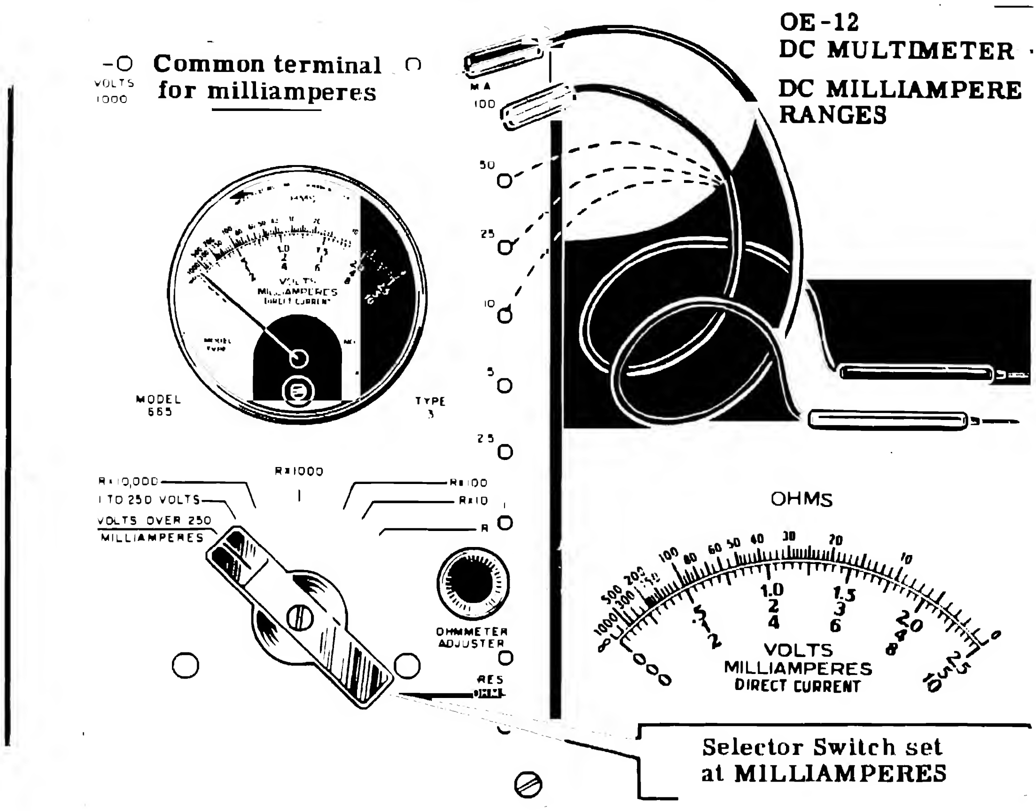
The meter dial is marked for three voltage scales to be read directly, 0-2.5 volts, 0-5 volts and 0-10 volts. When using the 0-1 volt range the reading indicated on the 0-10 volt scale is divided by 10. Readings for the 0-25 volt, 0-50 volt and 0-100 volt ranges are obtained by reading the 0-2.5 volt, 0-5 volt and 0-10 volt scales respectively and multiplying the reading by 10. Similarly the 0-250 volt, 0-500 volt and 0-1000 volt ranges are read on the 0-2.5 volt, 0-5 volt and 0-10 volt scales and the reading is multiplied by 100.



OE-12 DC MULTIMETER—
DC VOLTAGE RANGES

HALF-WAVE RECTIFIERS—DRY METAL TYPE

Demonstration—OE-12 DC Multimeter (continued)



Next, the instructor will show how the OE-12 is used as a milliammeter. The selector switch position marked VOLTS OVER 250 is also marked MILLIAMPERES. To use the OE-12 DC multimeter as a milliammeter, the selector switch is turned to this position for all of the milliampere ranges. The NEGATIVE meter lead is connected to the pin jack marked (—) at the top right corner of the meter case. The row of pin jacks marked MA. on the right side of the meter is used to select the milliampere range by connecting the POSITIVE meter lead to the pin jack marked with the desired range. (CAUTION: The two pin jacks marked RES OHMS at the bottom of the row are not used for milliampere ranges.)

The 0-2.5 ma., 0-5 ma. and 0-10 ma. ranges are read directly on the same scales as the corresponding voltage ranges. The 0-25 ma., 0-50 ma. and 0-100 ma. ranges are read on the 0-2.5 ma., 0-5 ma. and 0-10 ma. ranges respectively and the readings multiplied by 10 while the 0-1 ma. range is read on the 0-10 ma. scale and the reading divided by 10.

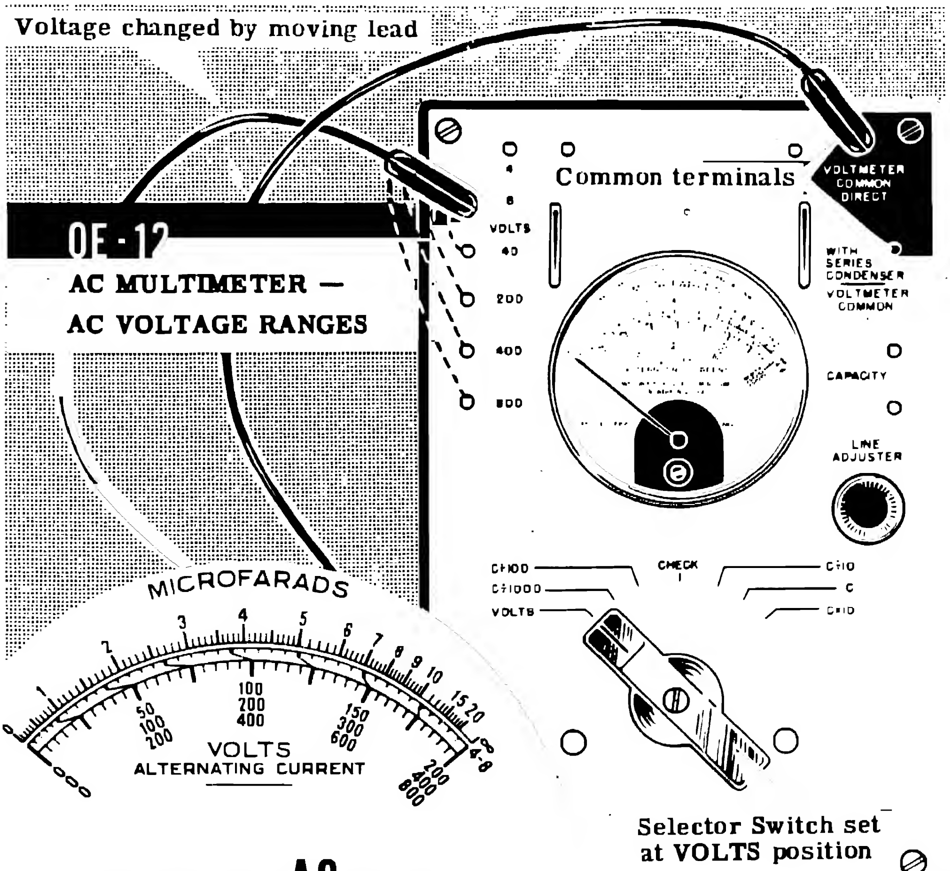
CAUTION: Make certain to observe polarity when using the OE-12 DC multimeter as a voltmeter or milliammeter. The (—) pin jacks on the meter case are the common negative terminals for all the voltage and current ranges, while the positive meter terminals are those marked with the volts or milliampere ranges.

Demonstration—OE-12 AC Multimeter (continued)

The use and operation of the OE-12 AC multimeter as an AC voltmeter is next demonstrated. This meter has six AC voltage ranges and is also used to test capacitor leakage and measure capacitance. You will find out about its use as a capacity meter a little later.

To measure AC volts, the selector switch is turned to the VOLTS position. One meter lead is connected to one of the common terminals on the upper right side of the meter case. If the AC voltage to be measured has no DC component the pin jack marked VOLTMETER COMMON DIRECT is used as the common terminal. If a DC component is present with the AC voltage to be measured, the pin jack marked WITH SERIES CONDENSER/ VOLTMETER COMMON is used as the common terminal.

The other meter lead connects to one of the pin jacks on the upper left side of the meter marked VOLTS. The pin jack used also indicates the range of the meter 0-4 volts AC, 0-8 volts AC, 0-40 volts AC, 0-200 volts AC, 0-400 volts AC or 0-800 volts AC. The meter range is changed by moving the meter lead to the pin jack marked with the range desired.



Selector Switch set at VOLTS position

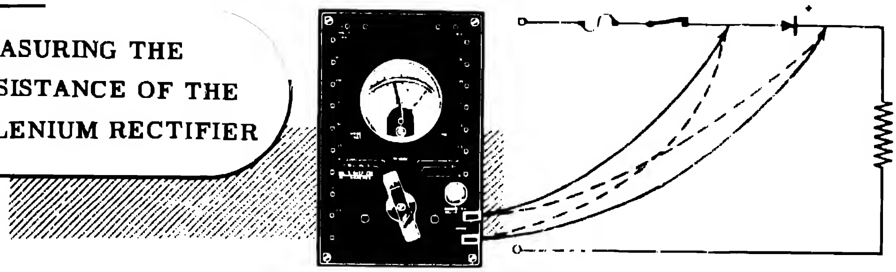
SCALES USED FOR AC VOLTS

HALF-WAVE RECTIFIERS—DRY METAL TYPE

Demonstration—Resistance Analysis of the Half-Wave Rectifier Circuit

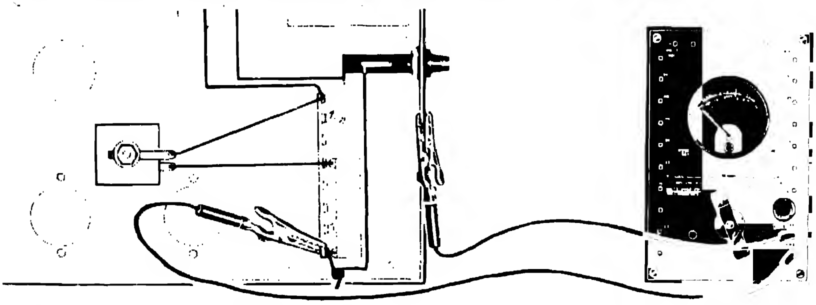
To check the selenium rectifier the instructor measures its resistance with the ohmmeter in both directions. You see that the two resistance values differ greatly, one being very much greater than the other, indicating that the selenium rectifier is in good condition.

MEASURING THE RESISTANCE OF THE SELENIUM RECTIFIER

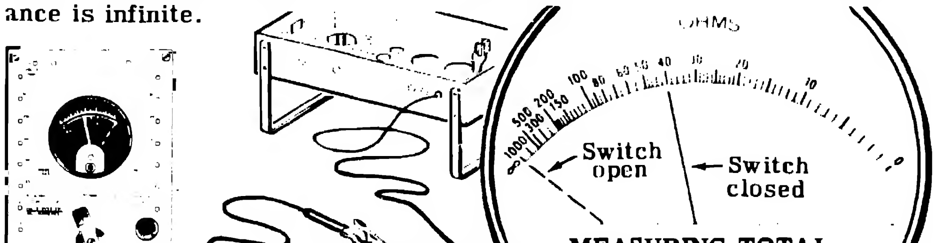


Since none of the parts or wiring used in the circuit is connected directly to the chassis, the resistance between the chassis and all points in the circuit is infinite. To check this resistance, the instructor sets the ohmmeter at its highest range and measures the resistance between the chassis and various points in the circuit.

CHECKING THE RESISTANCE BETWEEN THE CIRCUIT WIRING AND THE CHASSIS



With the circuit switch closed, the total circuit resistance across the line cord plug terminals should be between 40,000 and 400,000 ohms depending upon the ohmmeter connections. With the switch open, this resistance should be infinite. To check the total circuit resistance, the instructor measures the resistance across the line cord plug terminals with the switch closed. You see that the lowest resistance indicated is about 40,000 ohms. The circuit switch is opened and you see that the measured resistance is infinite.

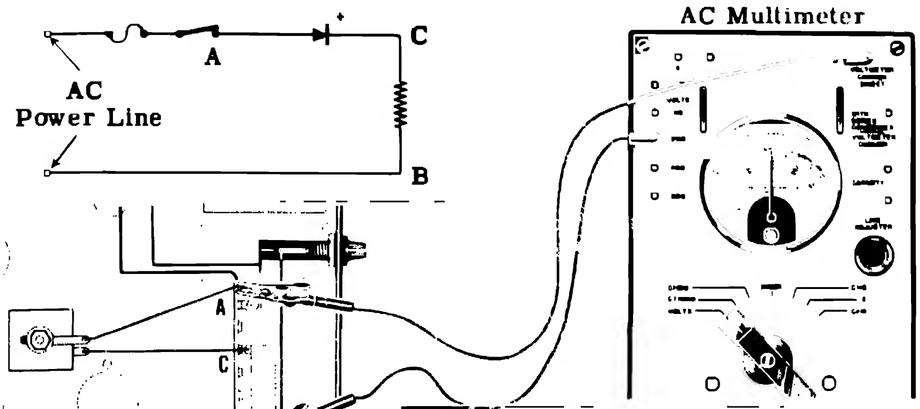


MEASURING TOTAL CIRCUIT RESISTANCE

HALF-WAVE RECTIFIERS—DRY METAL TYPE

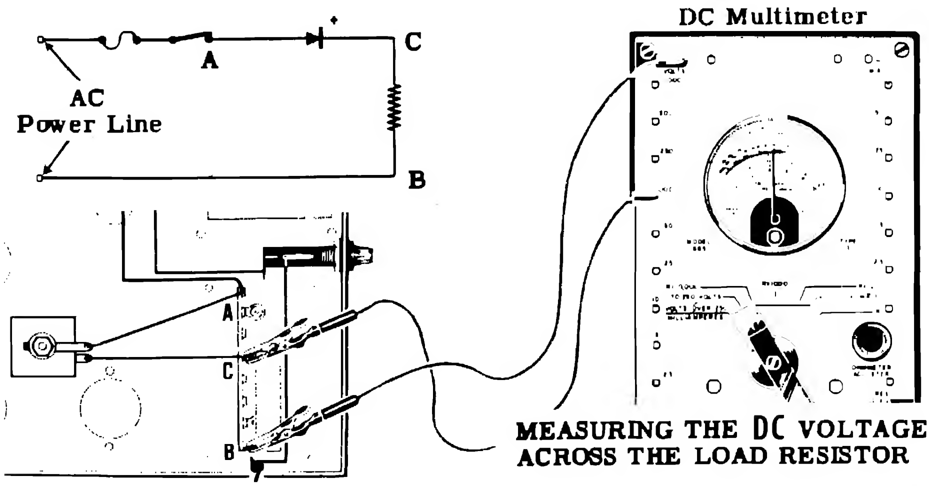
Demonstration—Voltage Analysis of the Half-Wave Rectifier Circuit

Next, the line cord plug is connected to the AC power line outlet and the circuit switch is closed. The instructor measures the voltage between points A and B in the circuit and you see that it is approximately 117 volts AC. This measurement is made with the OE-12 AC multimeter



MEASURING THE AC VOLTAGE APPLIED TO THE CIRCUIT

The voltage between points C and B is measured with the OE-12 DC multimeter. Since the meter reads the average DC value, the voltage measured is much less than 117 volts DC (approximately 50 volts). There is also a small drop in voltage due to the resistance of the rectifier. The two voltage measurements show that AC voltage applied to the circuit is changed to DC by the rectifier and the current flows through the load resistor in one direction only.



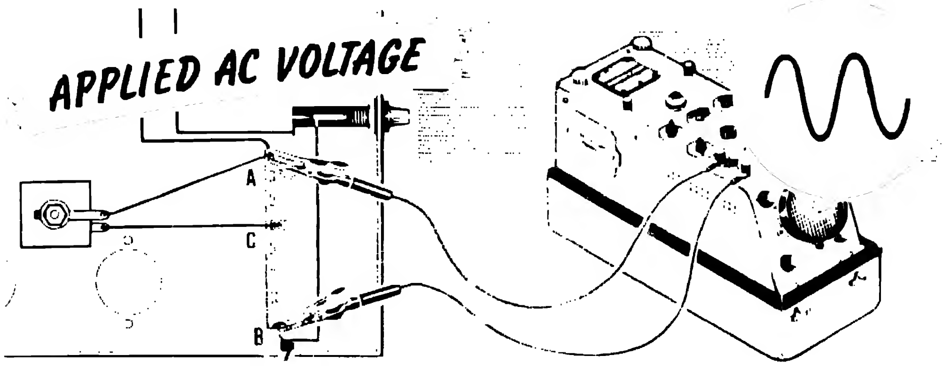
MEASURING THE DC VOLTAGE ACROSS THE LOAD RESISTOR

Safety precautions are particularly important when making voltage measurements in a circuit. The correct procedure and safety precautions to be observed are shown to you during this demonstration and should be followed at all times when working with electronic circuits.

HALF-WAVE RECTIFIERS—DRY METAL TYPE

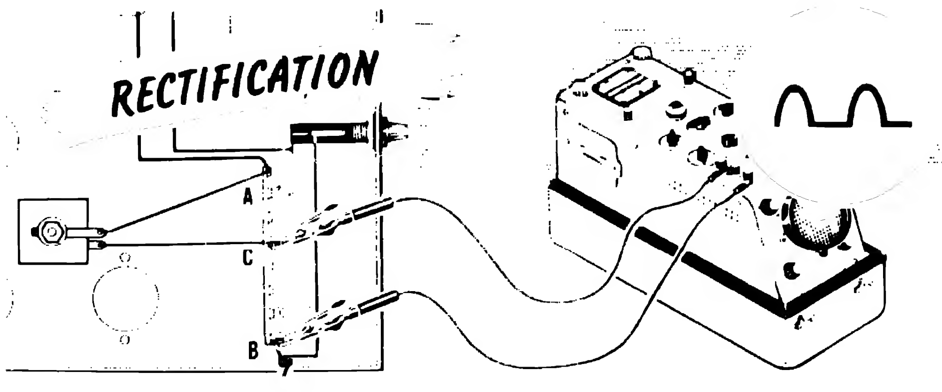
Demonstration—Waveform Analysis of the Half-Wave Rectifier Circuit

The oscilloscope is used to show the voltage waveforms present in the rectifier circuit. With no power applied to the circuit, the vertical input leads of the 'scope are connected to points A and B as shown. Power is then applied to the circuit and the 'scope controls are adjusted to obtain a waveform showing two or more complete cycles of the AC voltage applied. The instructor demonstrates the procedure used to obtain the waveform, and he reviews the operation of the 'scope and the effect of various 'scope controls on the observed waveform.



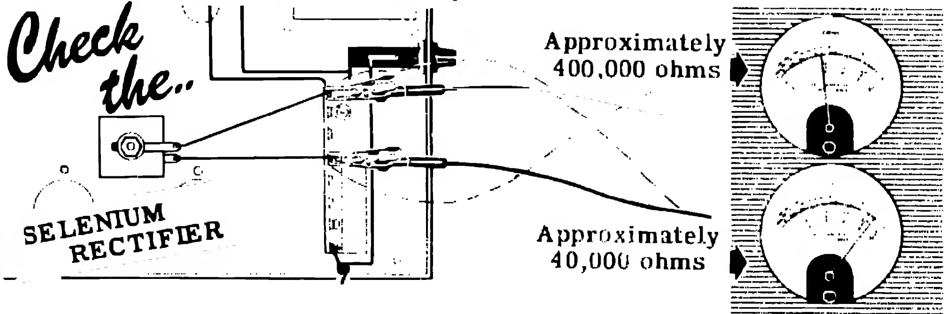
After observing the AC waveform of the applied line voltage at points A and B the power is removed from the circuit. Since the switch opens only one side of the AC power line, it is always advisable to remove the line cord plug from the power line outlet while the circuit connections are being changed. If the line cord plug is left in the power line outlet, a voltage may exist between part of the circuit and an external ground, since one side of the power line is always grounded.

The vertical input leads are connected across the load resistor, points C and B in the circuit, and power is again applied to the circuit. You see that the waveform of the voltage across the load resistor consists of half cycles of the previously observed waveform. This shows that the voltage across the load resistor rises and falls in one direction but does not reverse direction. The waveform then is pulsating DC and shows the effect of rectification in changing AC to DC.

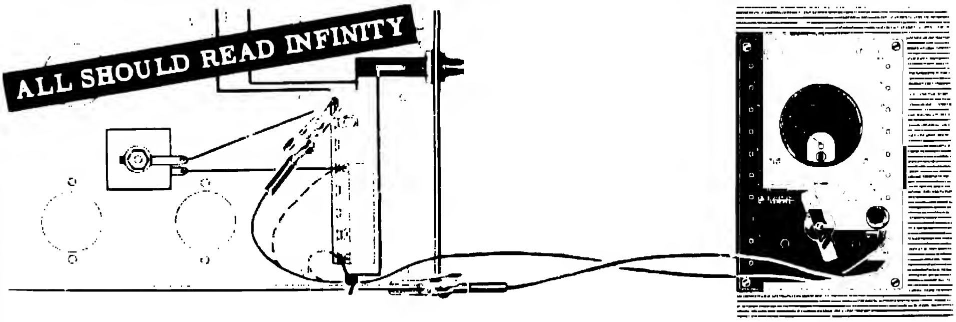


Experiment—Resistance Analysis of the Half-Wave Rectifier Circuit

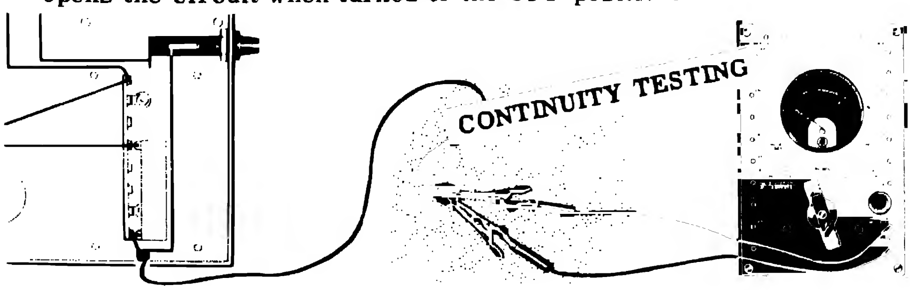
1. Measure the resistance of the selenium rectifier in both directions. Record the two resistance readings since the condition of the rectifier is indicated by these readings.



2. Measure the resistance between points A, B and C, and the chassis. The resistance readings should all be infinite. A lower reading indicates that some part of the circuit is grounded to the chassis and this trouble should be corrected before proceeding with the experiment.



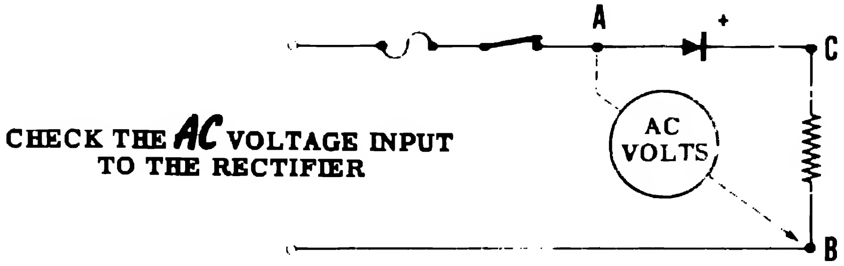
3. Connect the ohmmeter leads across the line cord plug terminals and measure the total circuit resistance, first with the switch opened, then closed. The ohmmeter leads should be reversed to find out which connection of the ohmmeter results in the lower resistance when the switch is closed. With the switch open the resistance should be infinite. When the switch is closed it should be about 40,000 ohms with the ohmmeter connected to obtain a minimum resistance. This resistance check is called "continuity testing" and is used to find out if the circuit is completed when the switch is closed. It also shows whether the switch opens the circuit when turned to the OFF position.



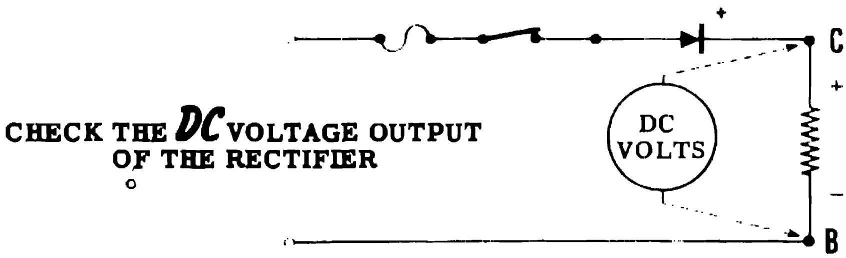
HALF-WAVE RECTIFIERS—DRY METAL TYPE

Experiment—Voltage Analysis of the Half-Wave Rectifier

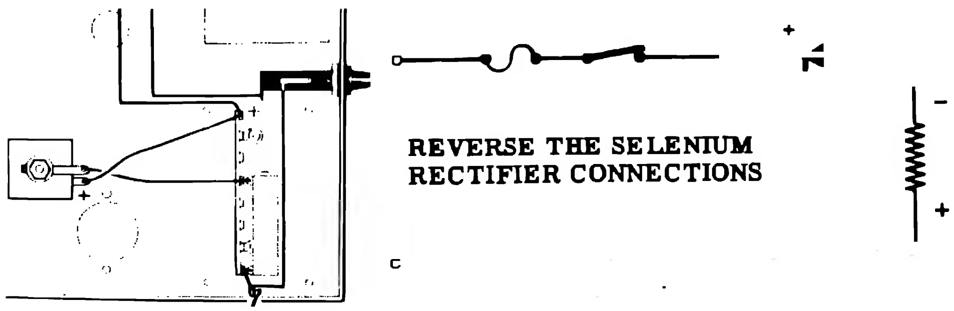
1. Connect the line cord to a 117 volt, 60 cycle AC power line outlet and measure the AC voltage applied to the circuit at points A and B. Use the 0-200 volts AC range of the OE-12 AC multimeter for this measurement.



2. Measure the DC voltage across the load resistor at points C and B. Use the 0-100 volts DC range of the OE-12 D` multimeter for this measurement. Proper polarity must be observed in taking this reading and the voltmeter polarity can be used as a check on the polarity of the DC output of the rectifier unit.



3. Remove the power from the circuit, then disconnect and reverse the terminals of the selenium rectifier. With the connections reversed repeat steps 8 and 9 and you see that the results are the same as those obtained previously except that the polarity of the DC voltage between points C and B is reversed. Remove the power applied to the circuit when your voltage measurements are completed and reverse the rectifier connections again.



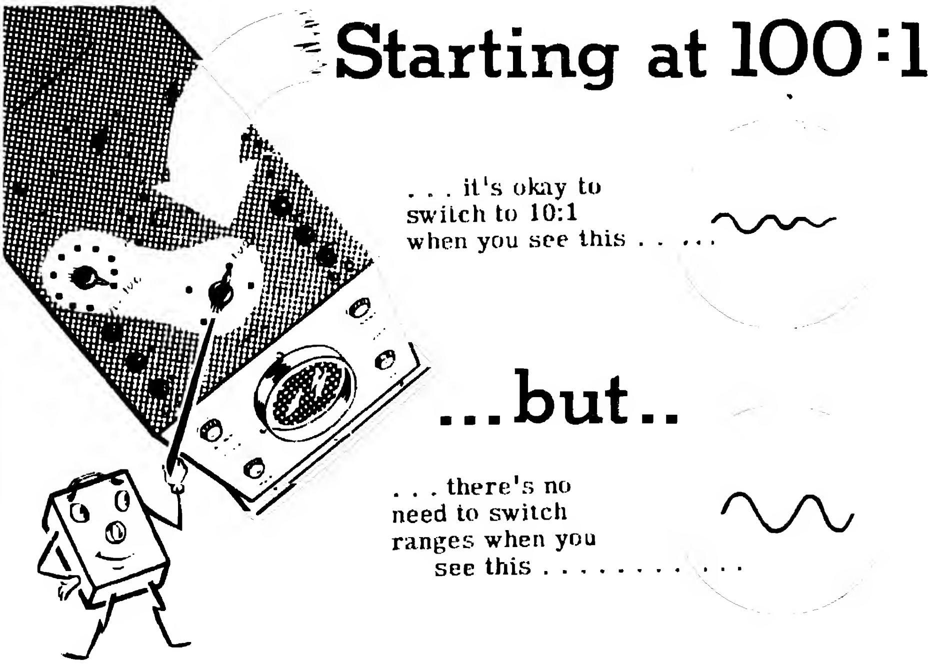
HALF-WAVE RECTIFIERS—DRY METAL TYPE

Experiment—Waveform Analysis of the Half-Wave Rectifier Circuit

Some oscilloscopes have both an attenuator and a vertical gain control. The purpose of the attenuator is to reduce the amplitude of the input signal before it is acted on by the vertical amplifier in the 'scope. The purpose of the gain control is to vary the size of the image on the 'scope screen. Incorrect use of these controls can cause distortion of the 'scope image to the point where it no longer resembles the signal at the test point.

This distortion occurs whenever too much signal is going into the vertical amplifier. There is a limit to the amount of signal that the amplifier can handle before it distorts the signal. Therefore, you should always make certain that you are not putting too much signal into the amplifier by setting the attenuator at the largest scale possible.

On an attenuator setting of 100:1, if the signal appears too small on the 'scope screen, turn the vertical gain control up until the waveform can be clearly seen. Only if the gain control cannot make the waveform large enough to be seen on the 100:1 attenuator setting, should you turn to the next lower attenuator range. Never use the 10:1 range unless the 100:1 range cannot be used. Similarly, never use the 1:1 range unless the 10:1 range cannot be used. Always use the largest attenuator range and you'll avoid distortion.



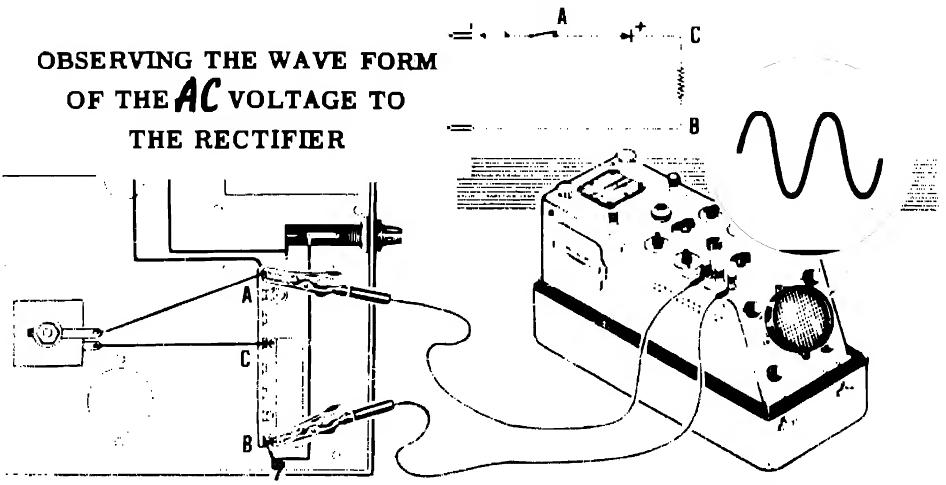
In oscilloscopes which have no attenuator control, the vertical gain control serves both the function of reducing the signal fed to the amplifier as well as the size of the image on the screen. Therefore, you can't make a mistake when using this type of oscilloscope—when the image is small enough to be seen on the screen, it is automatically small enough to be fed into the vertical amplifier.

HALF-WAVE RECTIFIERS—DRY METAL TYPE

Experiment—Wave Form Analysis of the Half-Wave Rectifier Circuit (continued)

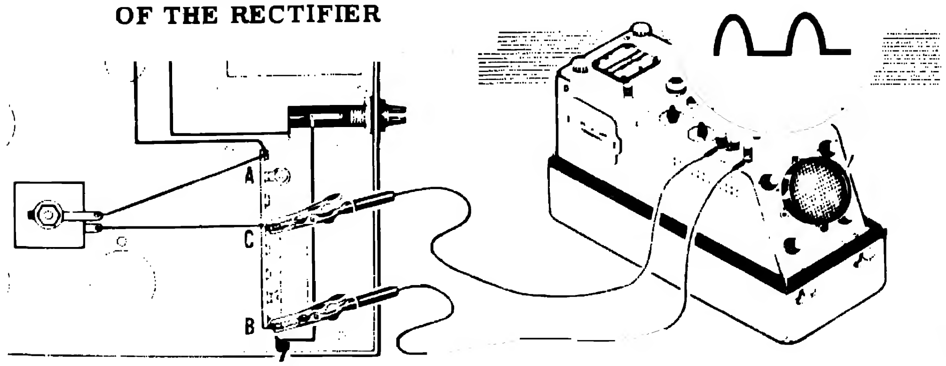
1. Connect the oscilloscope vertical input leads across points A and B to observe the wave form of the applied voltage. The VERT. ATTEN. control should be in the 100:1 position since the wave form amplitude to be observed is relatively high. With power applied to the circuit, adjust the 'scope controls to obtain a wave form showing two or more complete cycles of the AC voltage between points A and B.

OBSERVING THE WAVE FORM OF THE AC VOLTAGE TO THE RECTIFIER



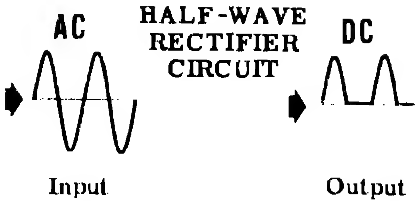
2. Remove the line cord plug from the AC power line outlet and move the 'scope input leads to points C and B in the circuit. Again apply power to the circuit and observe the pulsating DC voltage wave form across the circuit load resistor. Sketch the two wave forms observed, then remove the power applied to the circuit and disconnect the oscilloscope. Leave the rectifier circuit wired on the chassis since you will use it again for the next experiment.

OBSERVING THE WAVE FORM OF THE DC VOLTAGE OUTPUT OF THE RECTIFIER

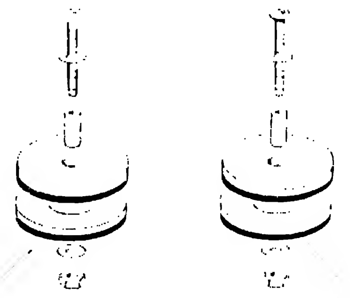


HALF-WAVE RECTIFIERS—DRY METAL TYPE

Review

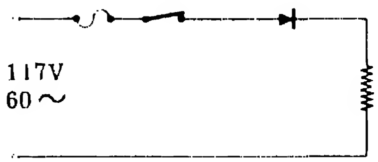


RECTIFICATION — When a device called a rectifier is placed in series with an AC circuit, it permits current to flow only in one direction, changing the applied AC voltage to pulsating DC. Rectification is the changing of AC to DC.

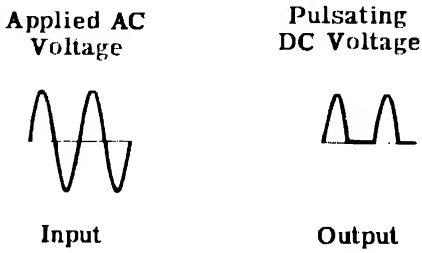


Copper-oxide Iron-selenium

DRY METAL RECTIFIERS — A rectifier consisting of two unlike metallic substances pressed together, which allows current flow in one direction only. Copper-oxide and iron-selenium combinations are usually used to construct dry metal rectifiers.



HALF-WAVE RECTIFIER CIRCUIT — A rectifier connected in series between an AC voltage source and the circuit load resistance. The rectifier changes the applied AC to a DC output voltage across the load resistance.



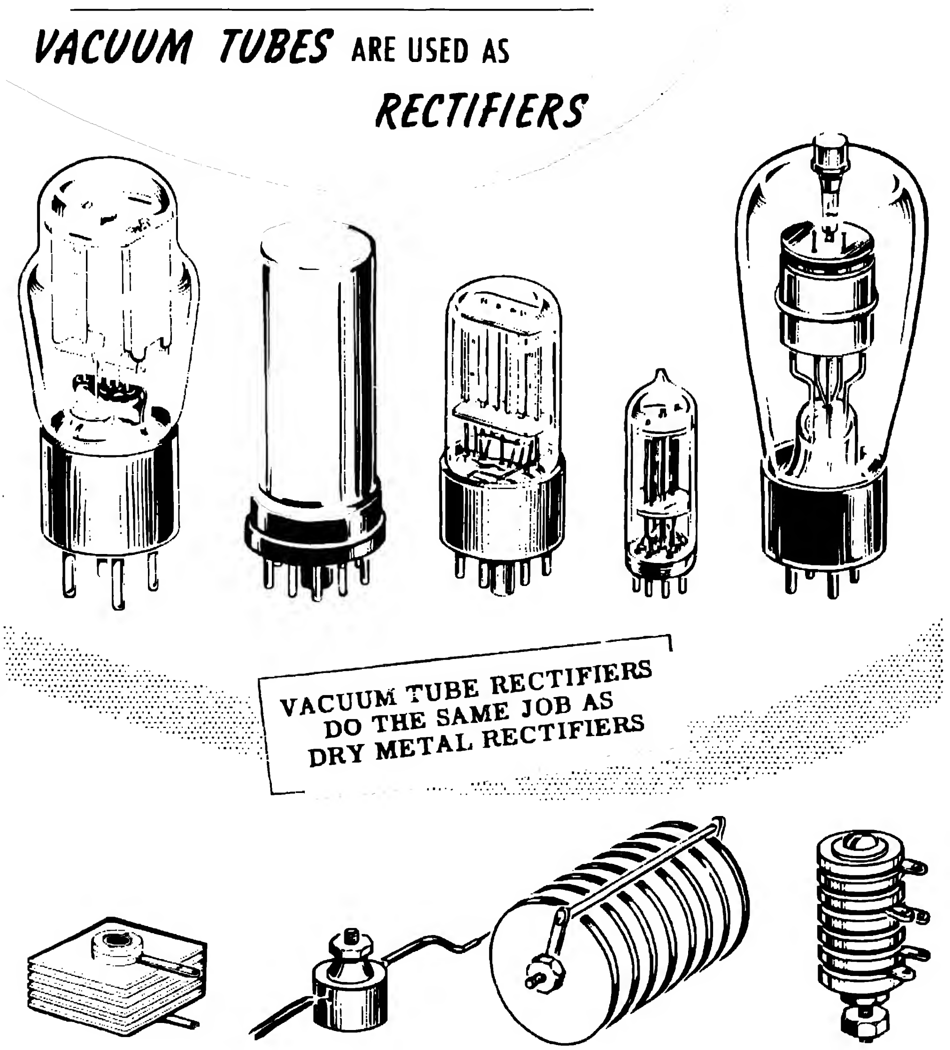
RECTIFIER CIRCUIT WAVEFORMS — If the applied voltage is an AC sine wave, the output waveform consists of half cycles of the applied AC voltage. This output waveform is a pulsating DC voltage.

HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

Vacuum Tubes

Dry metal rectifiers are used in many power supplies to change AC to DC but they are limited as to voltage and current rating. They are not normally rated at voltages greater than 130 volts AC. Low voltage units rated at 10 volts or less have a high current capacity, greater than 1 ampere, while the current capacity of higher voltage units is much less than 1 ampere.

Because of the voltage and current limitations of dry metal rectifiers, another type of rectifier, the diode vacuum tube, is often used in power supplies. As a rectifier, the diode vacuum tube operates in the same way as a dry metal rectifier, acting as a good conductor of current in one direction and as an insulator in the other direction. The diode vacuum tube also has many other uses in electronics which you will find out about later.

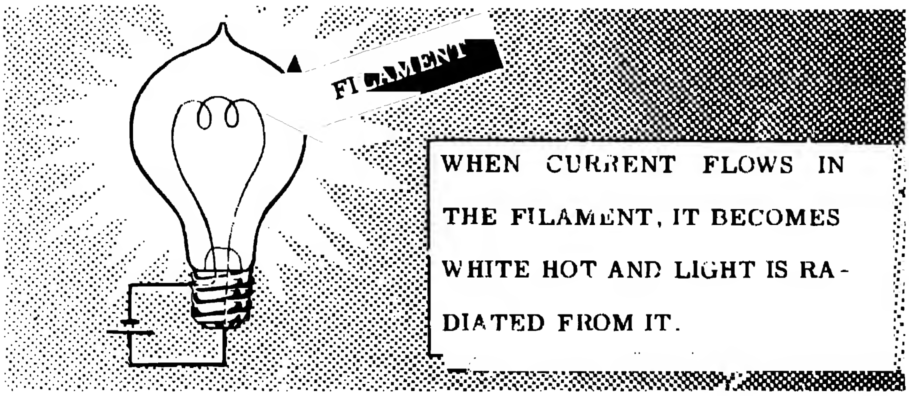


HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

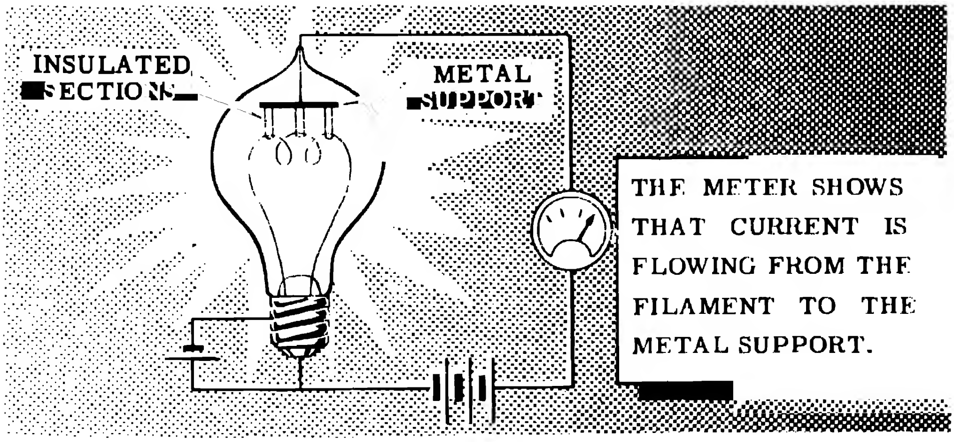
The Discovery of the Diode

The principle on which a diode is based was discovered some 70 years ago —before anything was known about electrons.

Thomas Edison was working on an experiment with his incandescent lamps in which a carbon filament was used. The filaments which he used broke too easily as they were constructed of thin threads or filaments of carbon.



In an effort to lengthen the life of his light bulbs, Edison constructed a metal support which he connected to the fragile filament by insulated sections. For some unknown reason, he connected the metal support to the positive side of a battery and the filament to the negative side. To his surprise, he noticed that a current was flowing.

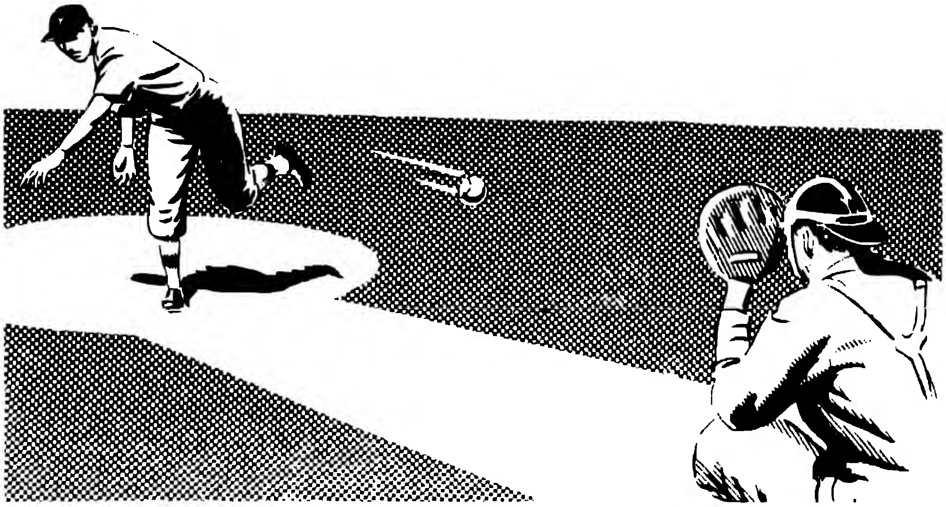


Since nothing was known about electrons, Edison could not understand or see any importance in his discovery and it took 21 years before Fleming, a British scientist learned the significance of this flow of electrons. Because he observed that current could flow only in one direction, Fleming called his vacuum tube a "valve." In fact, vacuum tubes are still called "valves" by the British.

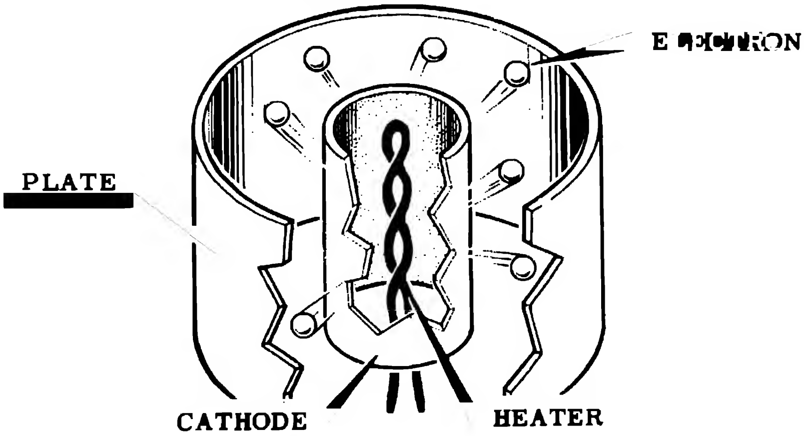
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

How a Diode Tube Works

The diode vacuum tube is like a game of baseball in which control is the important thing. An understanding of how a diode vacuum tube controls the flow of current is required to understand how a diode tube works as a rectifier.



The parts of a vacuum tube which directly control the flow of current are called elements. A heated element which gives up electrons is called the cathode. The plate is a cylindrical element surrounding the cathode which attracts electrons when it is positively charged. The cathode is heated by a filament of resistance wire called a heater, which is not considered to be an element since it does not directly control the amount of current flow from cathode to plate. A vacuum tube of the type illustrated is called a diode because it has only two elements, a cathode and plate.



In addition to preventing the filament from burning, removing the air from the tube prevents the air molecules from interfering with the flow of electrons from cathode to plate. Sometimes the air is replaced by an inert gas which aids rather than opposes the electron flow.

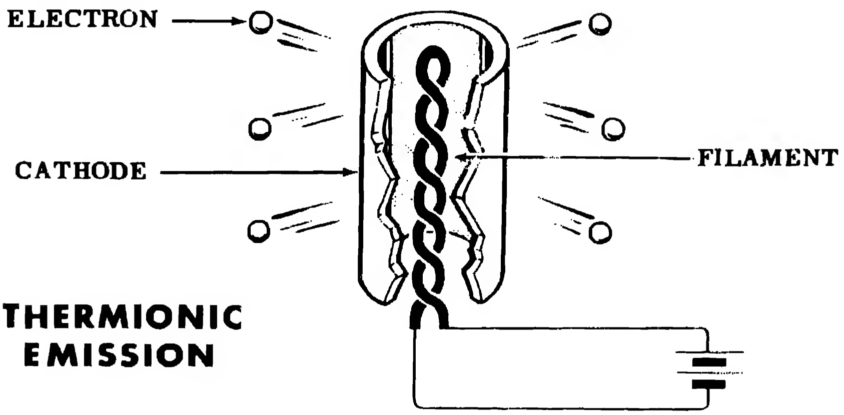
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

Electron Emission

The basic requirement of a diode vacuum tube is that there has to be a source of freely moving electrons which can be used to give us current flow. Of course, electrons are found in every atom of every substance but we still need a method of driving them out of the substance to make them freely moving.

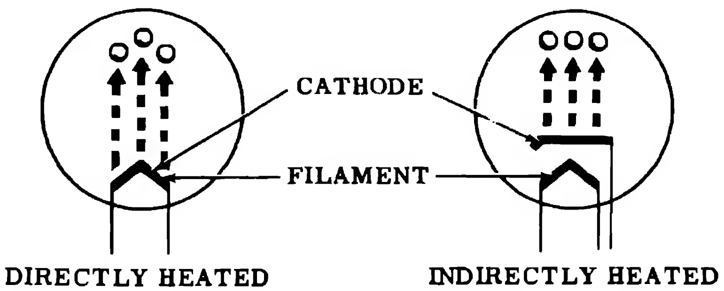
In Edison's set-up, the intense heat of the filament did the trick, and heat is used to do it in practically all the vacuum tubes you will see in the Navy or elsewhere. Driving electrons out of a substance by heat is known as "thermionic emission."

In the illustration, you will notice that the cathode is a cylinder or "sleeve" which surrounds, but does not touch, the filament. The filament is heated by the current flowing in it and the cathode is heated because it is so close to the filament. This arrangement of parts is known as an indirectly heated cathode.



THERMIONIC EMISSION

Some tubes such as the Fleming's Valve or the type 80 rectifier tube have what is known as directly heated cathodes, which means that there is no sleeve around the filament and the filament is itself the electron emitter.

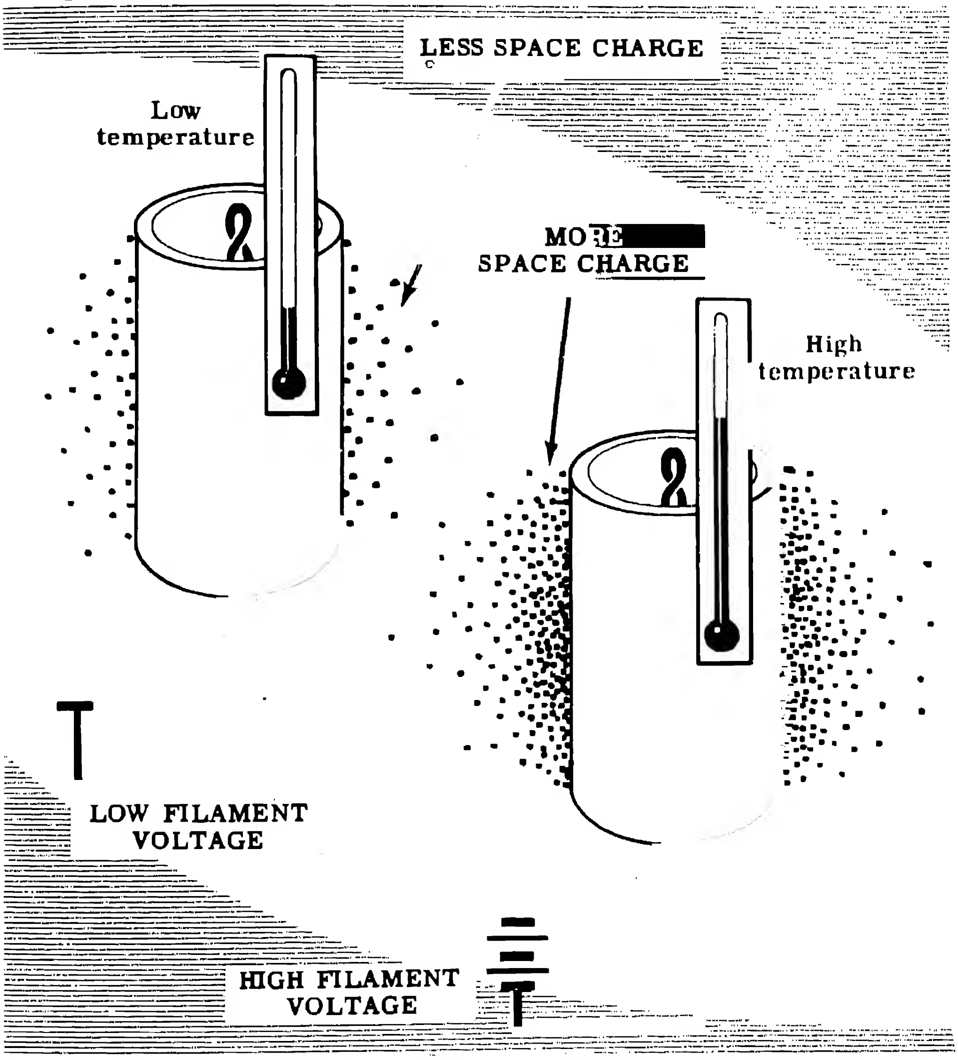


Because they can emit many more electrons than the indirectly heated type, directly heated cathodes are used in vacuum tubes designed for power supplies which supply high currents. Indirectly heated cathodes are more frequently used in low-current power supplies. Having the heater (filament) and the electron emitter (cathode) separate in an indirectly heated tube allows for the separation of the filament's and the cathode's electrical circuits.

HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

Electron Emission (continued)

If the cathode and filament were alone in the glass tube, the emitted electrons would form a cloud called "space charge" around the cathode. Like the electrons in it, the space charge is negatively charged and therefore tends to repel other electrons and to keep more electrons from being emitted by the cathode. After a while, a balance would be reached between the tendency of the cathode to emit electrons and that of the space charge to repel them.



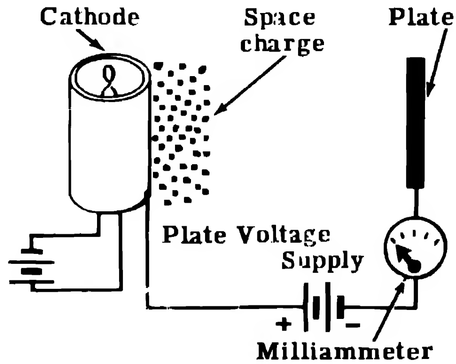
To increase the emission of electrons, you would have to raise the cathode's temperature by increasing the filament current. If, on the other hand, the cathode's temperature is lowered, the space charge will force some of its electrons to re-enter the cathode, resulting in decreased emission. The heater voltage for a tube is usually fixed. Various types of tubes operate with AC or DC heater voltages in the range from 1.25 to 117 volts.

HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

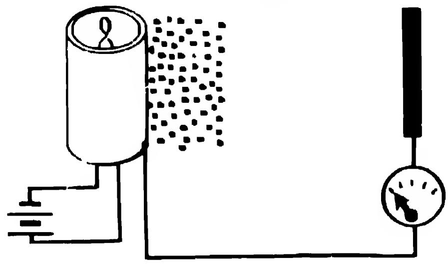
How Current Flows in a Diode

When a positively charged plate is placed around the cathode, the electrons are attracted from the space charge. The number of electrons which flows to the plate depends on the plate voltage with respect to the cathode.

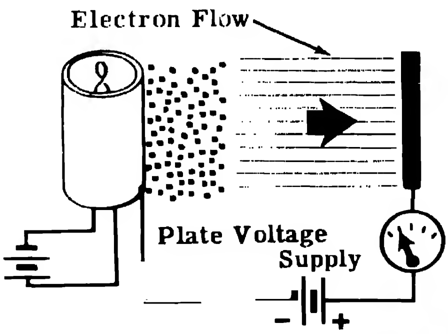
When the plate is more negative with respect to the cathode, no current flows from cathode to plate because the negative plate repels the electrons. Current cannot flow from the plate to the cathode, since the plate does not emit electrons.



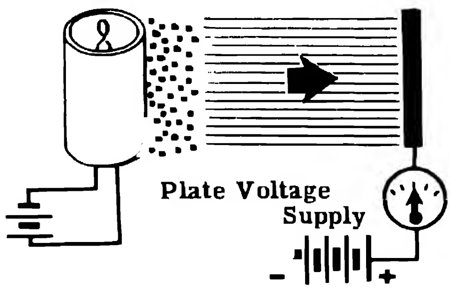
When the plate and cathode are at the same potential, the plate neither attracts nor repels electrons —— the current is still zero.



As soon as the plate becomes positive with respect to the cathode, current will flow from the space charge.



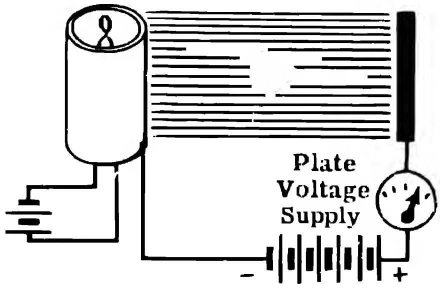
If this plate voltage is doubled, the current which flows is also doubled. This is the normal way for a diode to work: as long as the plate is positive with respect to the cathode, every change in plate voltage causes a corresponding change in plate current.



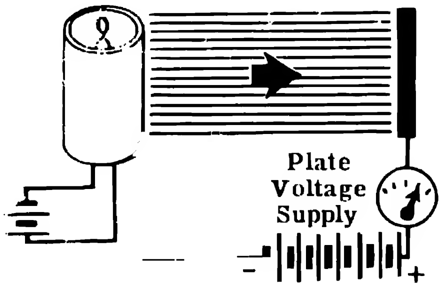
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

How Current Flows in a Diode (continued)

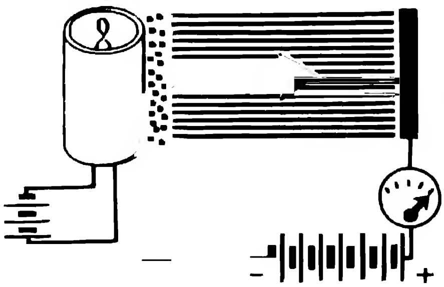
Now that the plate is very positive with respect to the cathode, the milliammeter indicates that a very large current is flowing. The plate is attracting the electrons as fast as the cathode can emit them.



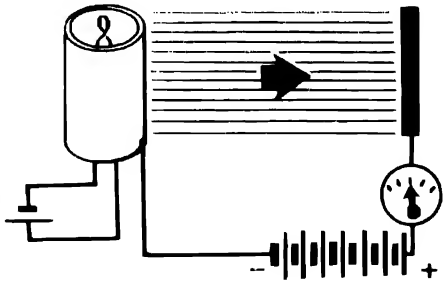
At this point, a further increase in plate voltage does not result in any additional current. The current does not increase because the cathode is emitting all the electrons it can. It is NOT normal to operate a diode at such a high plate voltage that changes in plate voltage do not produce changes in plate current.



If we now increase the filament voltage above its normal value, we enable the cathode to emit more electrons and, with the same plate voltage as before, we observe that a larger plate current is flowing.



If we had reduced the filament voltage, the current would have decreased because the cathode could not emit as many electrons as before. In practice, the filament voltage is not varied. Changes in plate current are achieved by varying the plate voltage as already described. However, after a tube has been used for some time, the cathode's emission decreases and the result is the same as if the filament voltage were decreased.

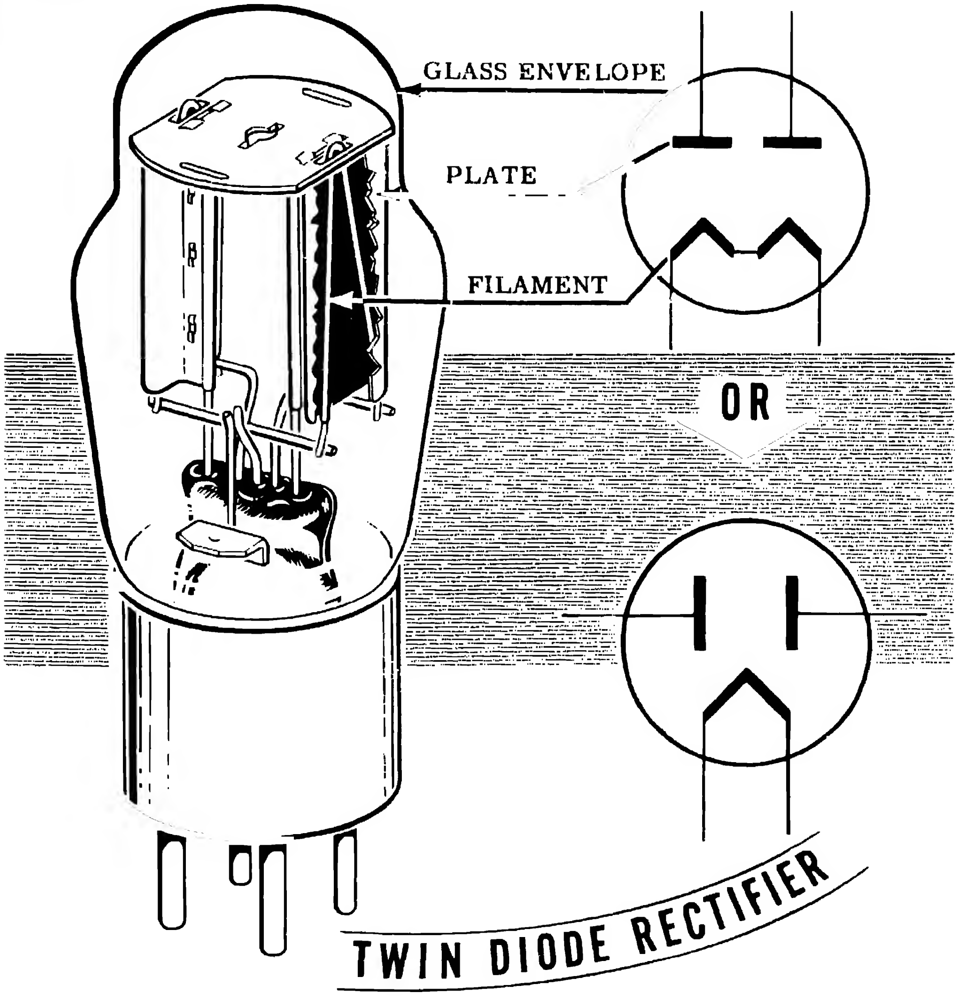


HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

The Rectifier Tube

The process of changing AC into DC is called "rectification." To change AC to DC a device must be used which will permit current flow in one direction only. A diode vacuum tube is such a device, permitting current to flow only from the cathode to the plate. Current does not flow from the plate to the cathode because the plate is not heated and therefore does not emit electrons. Since the plate will not emit electrons but will, when positive, attract electrons from the cathode space charge, the diode is a conductor only from cathode to plate and not from plate to cathode.

Any diode will rectify AC into DC but some are especially designed for use in power supplies and these are referred to as rectifier tubes. A typical rectifier tube with its schematic symbol is illustrated below. It is a twin diode (two diode tubes in the same glass envelope) and has a directly heated cathode. A filament which also acts as the cathode is suspended inside each metal plate and the two filaments are internally connected in series.



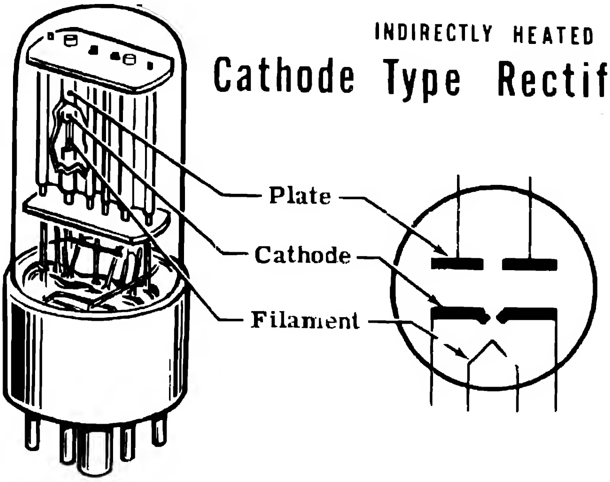
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

The Rectifier Tube (continued)

Some rectifier tubes have indirectly heated cathodes. A typical tube of this type is illustrated below. Vacuum tubes of all types are identified by number and the numbering system, which you will find out about later, indicates certain characteristics of the tube. The rectifier illustrated on the preceding sheet is a type 80 tube and the one illustrated below is a 117Z6-GT.

INDIRECTLY HEATED

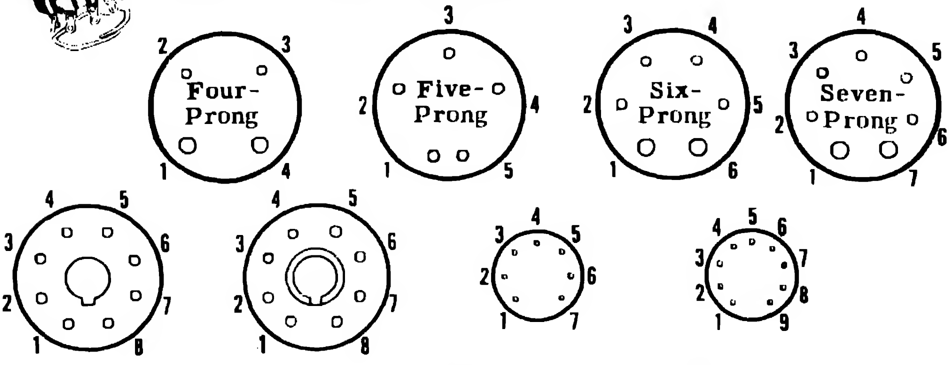
Cathode Type Rectifier Tube



Vacuum tubes are constructed with a plug-in base which fits into a socket. The socket is permanently wired into the circuit and the tube is removable and easily replaced. Vacuum tubes have a relatively short life as compared to other components used in electronic equipment and a method of easy replacement is required.

Although many special types of sockets are used, most of the vacuum tubes used in electronics require one of the eight sockets illustrated below. One method of classifying tubes is according to the socket required. The pin numbering system is also illustrated and refers to the bottom side of the socket since the circuit wiring is done on that side.

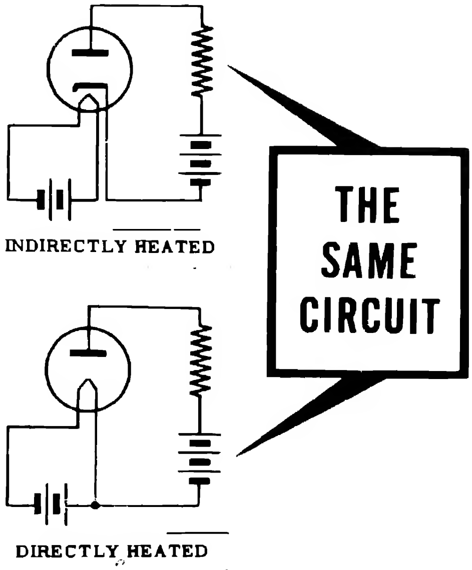
Vacuum Tube Sockets



HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

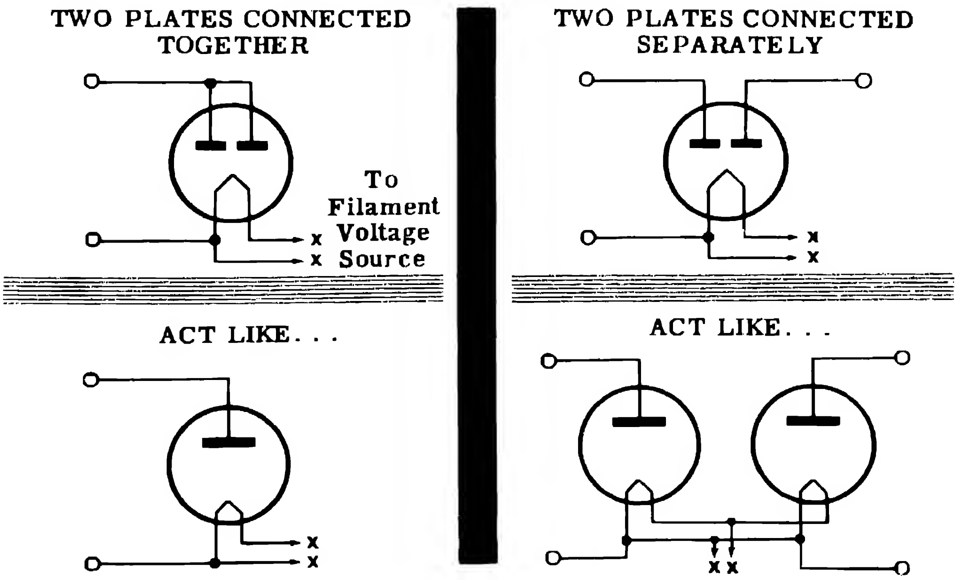
The Rectifier Tube (continued)

In an indirectly heated tube, the cathode and filament are separate structures and are connected to separate circuits. In a directly heated tube, the filament replaces the two structures, and is connected to two circuits. The filament wires are connected across a low voltage of about 5 volts which heats the filament and causes thermionic emission. In addition, one of the filament wires is connected to the circuit to which a cathode would be connected if the tube were indirectly heated.



There are two different ways of using a rectifier tube which has two plates and one filament. If both plates are connected together, the tube is acting the same as one diode because, in effect, you have only increased the plate area.

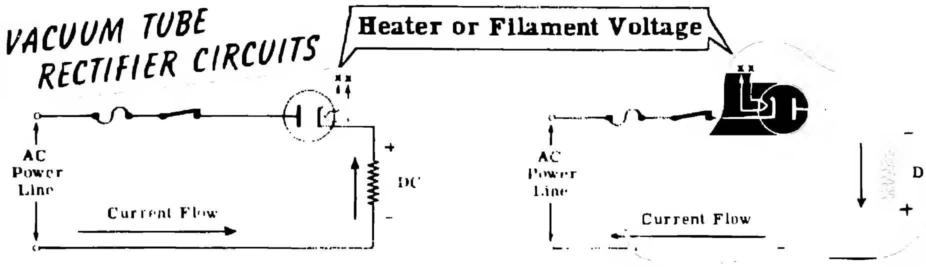
The other way is to connect the plates separately to different parts of the circuit. In this way the plates will not be at the same voltage and the effect is the same as using two separate diodes with the cathodes (or filaments) connected together. No matter how the connections are made, each plate will draw current only when it is positive with respect to the filament.



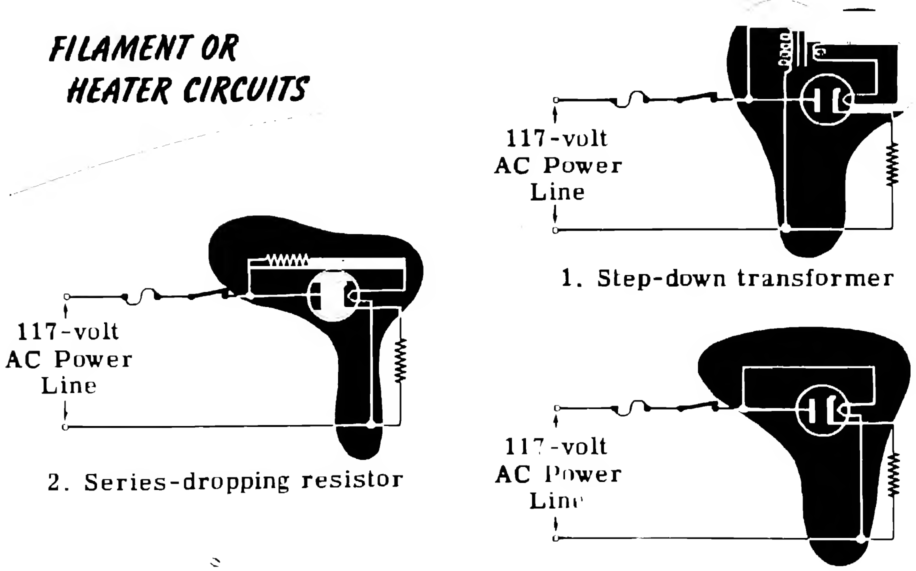
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

A Half-Wave Vacuum Tube Rectifier Circuit

A diode rectifier tube may be used in the half-wave rectifier circuit in place of a selenium rectifier if there is a voltage source available to supply the filament current required by the rectifier tube. The basic rectifier circuit using a vacuum tube rectifier is illustrated below. If the plate and cathode connections are reversed the polarity of the DC output voltage is reversed.



The rectifier tube filament circuit requires an additional source of filament voltage not required by the selenium rectifier—otherwise the operation of the circuit is identical to that of the basic dry metal rectifier circuit. Rectifier tube filaments are rated in volts and amperes so that the filament must be connected to a voltage source of the rated voltage and current. Filament or heater voltages are normally obtained from a step-down transformer or by using a series resistor to drop the line voltage to the correct value. Tubes having heaters rated at the same current are sometimes connected in series across the AC power line. Some rectifier tube heaters are rated at 117 volts and may be connected directly across the AC power line.



1. Step-down transformer

2. Series-dropping resistor

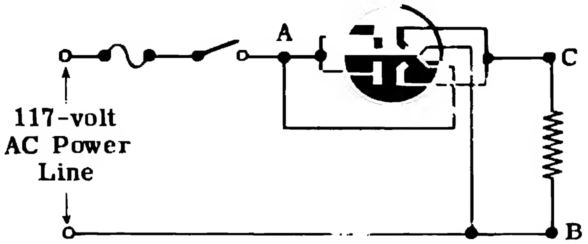
3. 117-volt heater connections

HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

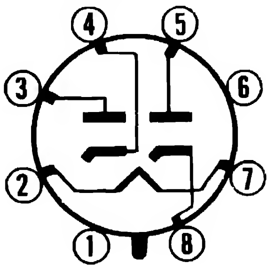
Vacuum Tube Circuit Wiring

In electronic circuit diagrams, vacuum tubes like other parts are represented by symbol. Usually the symbol shows only the connection of the tube elements to various parts of the circuit. To wire the socket, it is necessary to refer to a tube manual which shows the pin numbers of each tube element. In the illustration below a 117Z6-GT is shown in the circuit diagram with the plates and cathodes connected together to form a single diode. The tube base diagram of the type found in a tube manual and the actual wiring connections for the socket are shown below.

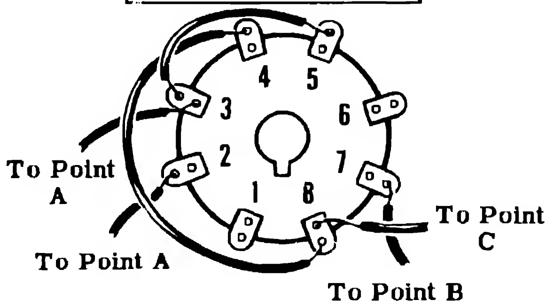
WIRING A 117Z6-GT TUBE SOCKET



Base diagram from tube manual

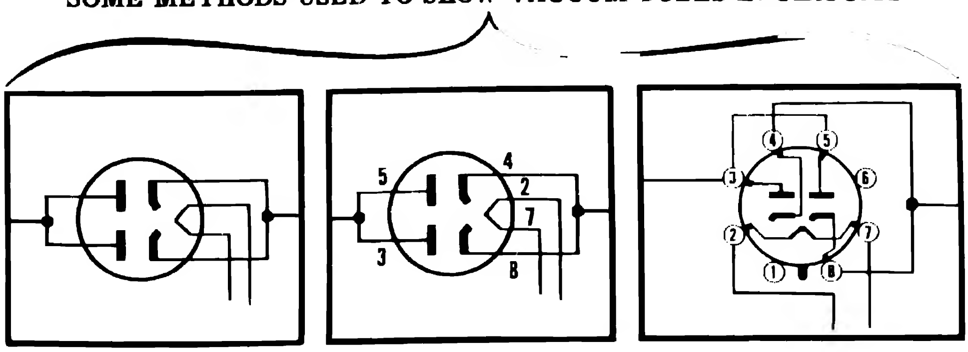


Actual socket wiring



There is a wide variation in the method of representing a vacuum tube in a circuit diagram and tube pins as well as elements are sometimes indicated.

SOME METHODS USED TO SHOW VACUUM TUBES IN CIRCUITS



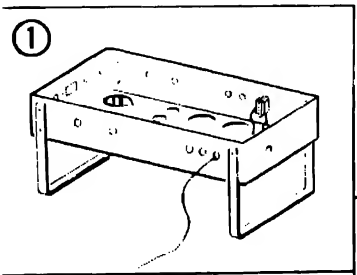
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

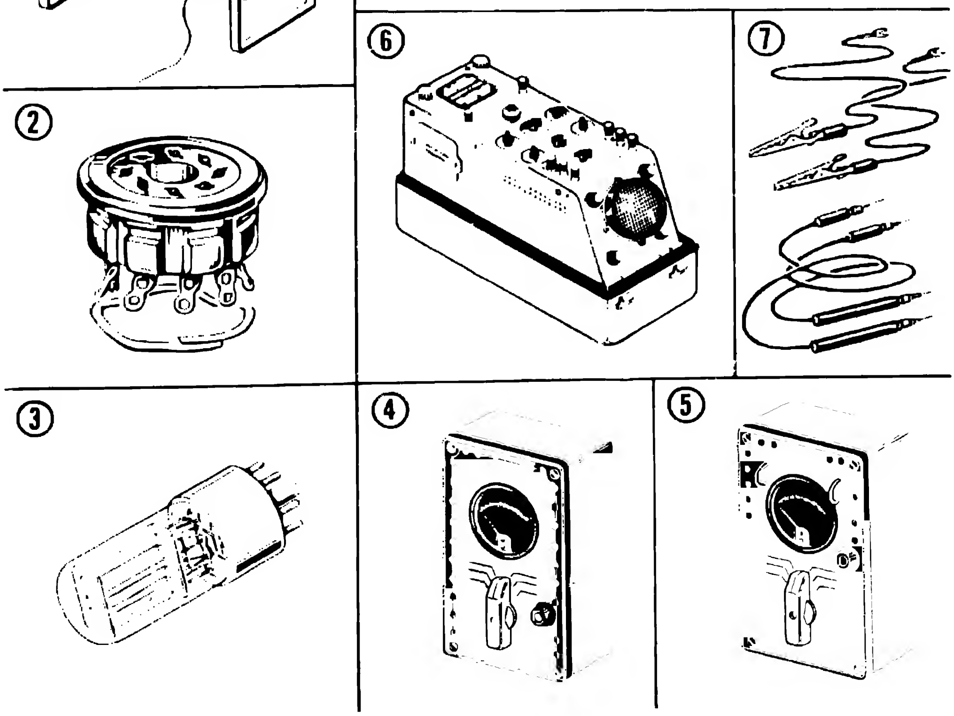
Experiment on the Vacuum Tube Rectifier Circuit

In performing this experiment, you will replace the selenium rectifier with a vacuum tube in a basic rectifier circuit. You will test the circuit and observe the wave form of the rectified voltage.

This is What You Will Need

1. Assembled basic rectifier circuit.
2. Octal socket.
3. 117Z6-GT rectifier tube.
4. OE-12 DC multimeter
5. OE-12 AC multimeter
6. OS-8A/U oscilloscope
7. Assorted test leads





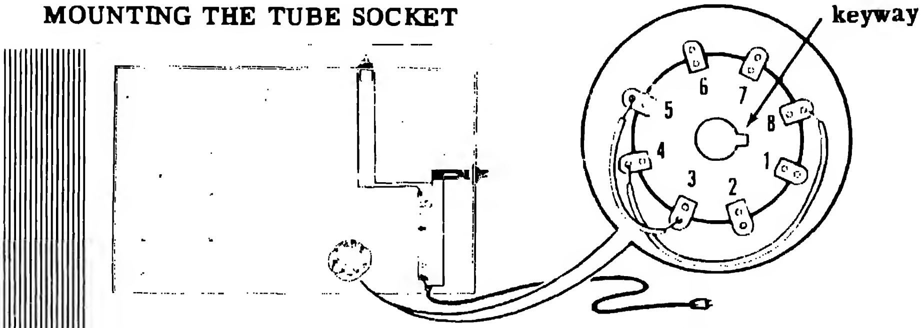
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

Experiment—Mounting and Wiring the Rectifier Tube Socket

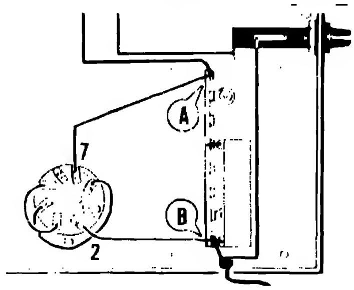
The instructor will demonstrate the techniques of wiring the diode vacuum tube rectifier circuit. To show the correct method of mounting sockets, the instructor mounts an octal socket in the socket hole nearest the terminal strip. The socket could be mounted in any number of positions, but to make wiring both easy and neat, it is positioned with the keyway towards the terminal strip.

Since the 117Z6-GT is to be used as a single diode, both the plates (pins 3 and 5) and cathodes (pins 4 and 8) are connected together. Short pieces of hook-up wire are used to make these connections as illustrated. In wiring to the socket soldering terminals or pins, the wire should be bent only once to add strength to the connection. Twisting the wire around the socket pin may break the pin or short out adjacent pins.

MOUNTING THE TUBE SOCKET

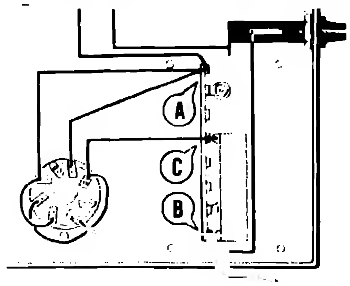


WIRING THE HEATER CIRCUIT



The filament or heater circuit normally is wired first. Pin 2 is connected to point B and pin 7 is connected to point A in the circuit. This connects the 117 volt heater of the 117Z6-GT directly across the AC power line whenever the switch is turned on.

WIRING THE PLATE AND CATHODE CIRCUITS



To replace the selenium rectifier the tube elements are connected between points A and C in the circuit. For + output at point C the plates (pins 3 and 5) are connected to point A and the cathodes (pins 4 and 8) are connected to point C. Since the plates and cathodes are connected together. pin 5 is used as the rectifier plate and pin 8 as the cathode.

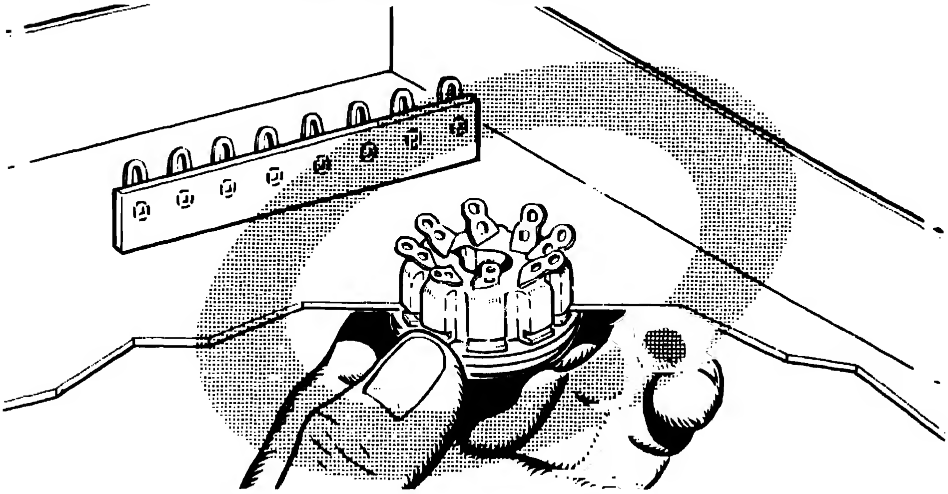
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

Experiment—Building the Vacuum Tube Rectifier Circuit

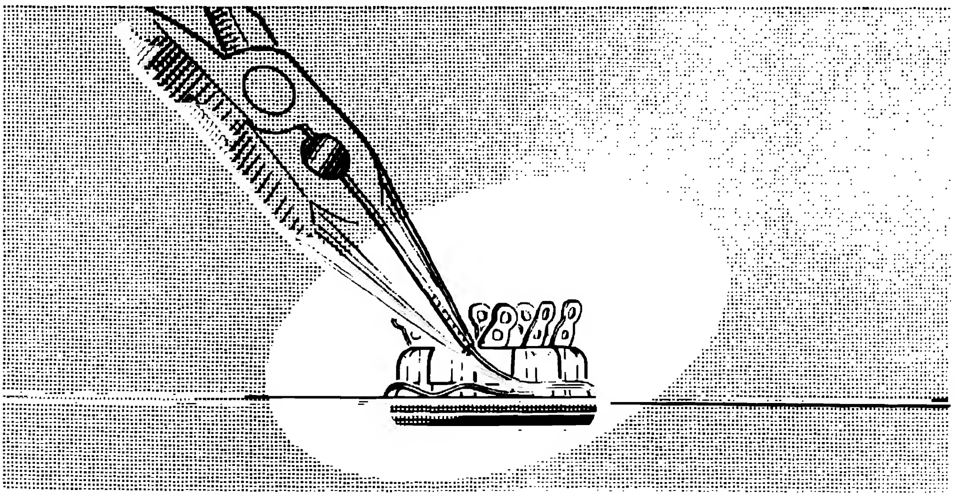
1. Disconnect and remove the selenium rectifier from the circuit. Leave all other parts and wiring connected.

2. Mount an octal socket in the socket hole nearest the terminal strip. The previous sheet shows a bottom view of the chassis with the location of the octal socket and other parts required for the circuit.

   The socket is put into the chassis hole from the top of the chassis with the prongs going through the hole. Turn the keyway of the tube socket so that it is facing towards the terminal strip.



Press the chassis top against the top of the work bench so that the pressure holds the socket in position. With the pliers, slip one end of the split locking ring into the groove of the socket and, working away from this point press the locking ring into the groove. When the free end of the locking ring slips into place, the tube socket is locked to the chassis. Later other tube sockets will be mounted on the chassis using this same method.



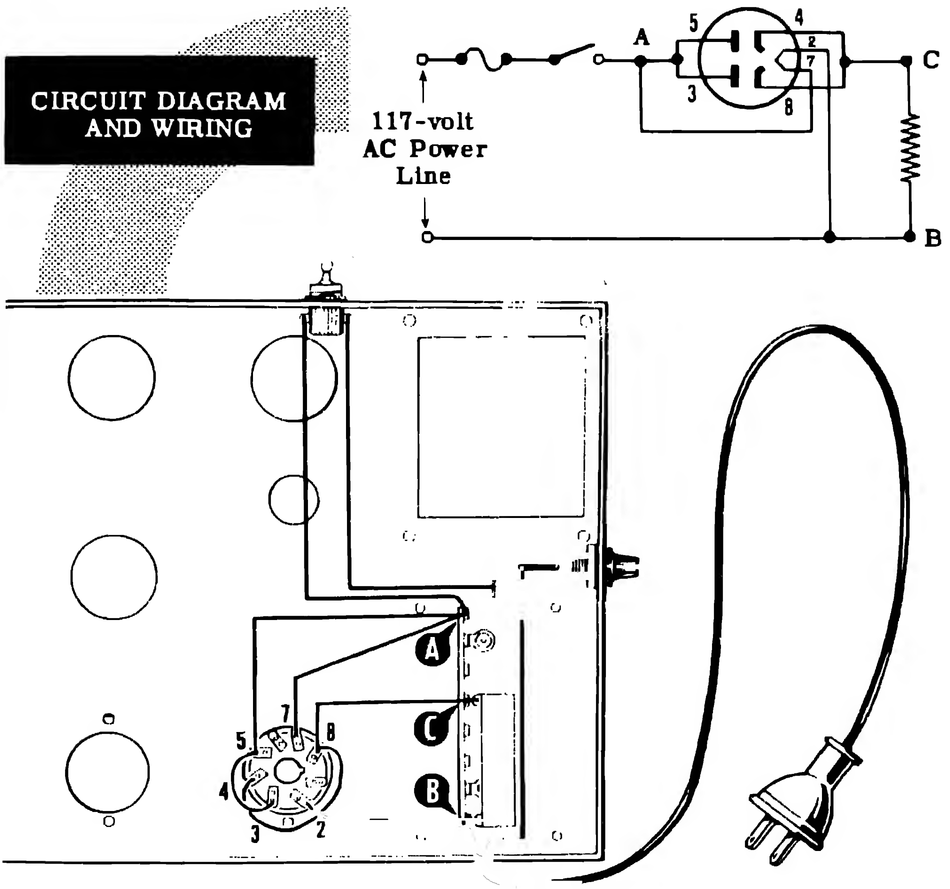
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

Experiment—Building the Vacuum Tube Rectifier Circuit (continued)

2. Complete the circuit wiring as follows:
   a. Connect socket pins 3 and 5 together.
   b. Connect socket pins 5 and 7 to point A.
   c. Connect socket pin 2 to point B.
   d. Connect socket pins 4 and 8 together.
   e. Connect socket pin 8 to point C.

   Check the completed wiring against the circuit diagram.

CIRCUIT DIAGRAM AND WIRING



3. Insert a 117Z6-GT rectifier in the socket, turning the tube until the key on tube base slides into the keyway of the socket. Using the OE-12 DC multimeter check the resistance between the chassis and point C. Since no part of the circuit is grounded to the chassis, this resistance reading should be infinite. If it is not infinite you have made a mistake in wiring—recheck the circuit against the diagram. Before applying power to the circuit measure the resistance across the rectifier circuit output, points B and C. If a reading of about 2,000 ohms is obtained, power may be applied to the circuit. If a much lower or higher reading is obtained check your wiring and parts again.

HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

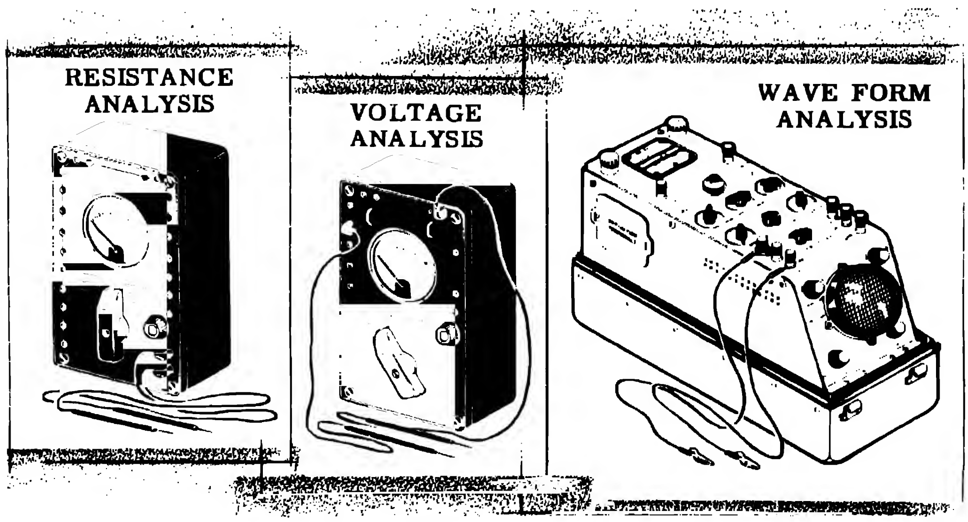
Checking and Observing Circuit Operation

To test and observe the operation of any circuit three methods are usually used—resistance analysis, voltage analysis and wave form analysis. Resistance analysis shows whether the wiring agrees with the circuit diagram and whether it is safe to apply power to the circuit. Voltage analysis shows whether the correct voltages are applied to the various parts of the circuit and whether voltage variations occur while the circuit is operating. Wave form analysis shows the wave form of voltages in various parts of the circuit and the effect of circuit operation on the wave form. For a complete check of circuit operation these three types of circuit analysis are used as follows:

1. Resistance analysis before applying power—
   a. To determine whether shorts exist
   b. To determine whether a connection (continuity) exists where it is as indicated on the circuit diagram
   c. Whether switches operate properly
   d. Condition of circuit components
   e. Whether it is safe to apply power

2. Voltage analysis with power applied—
   a. To determine whether the correct AC and DC voltages are present in all parts of the circuit
   b. To locate defective parts or incorrect wiring if voltages are incorrect.
   c. To determine whether voltages indicate normal circuit operation before observing the wave forms

3. Wave form analysis with power applied—
   a. To determine the effect of circuit operation on the wave form of the applied voltage
   b. To check whether the effect obtained is correct for normal circuit operation



HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

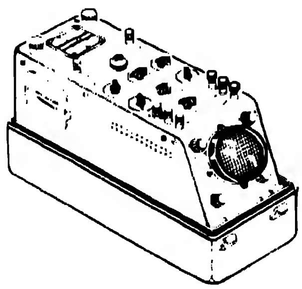
Demonstration—Testing the Vacuum Tube Rectifier Circuit

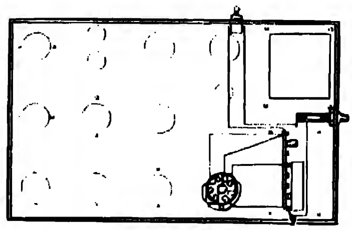
The purpose of this demonstration is to acquaint you with the procedure used in testing the half-wave vacuum tube rectifier circuit you have built. The instructor demonstrates three types of tests that you will use in the future—resistance checks, voltage checks and wave form analysis.

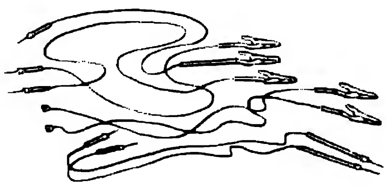
THIS IS WHAT IS NEEDED ...

1. OS-8A/U oscilloscope
2. AC and DC multimeters
3. Chassis with half-wave rectifier circuit
4. Assorted test leads

Note: These items are also needed in the experiment which follows.





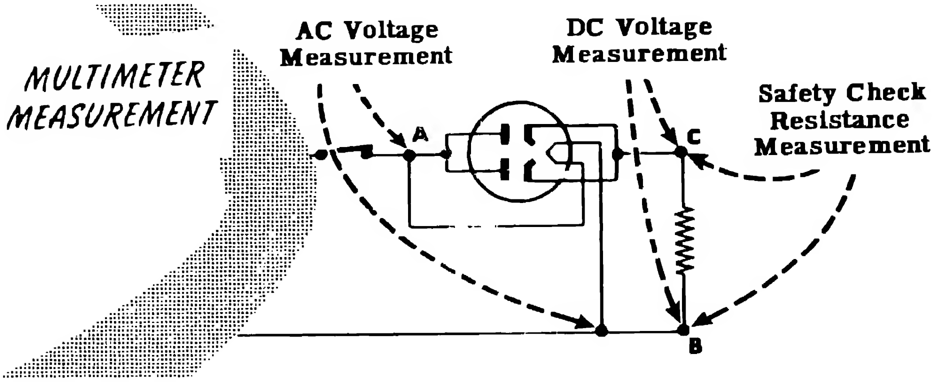


HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

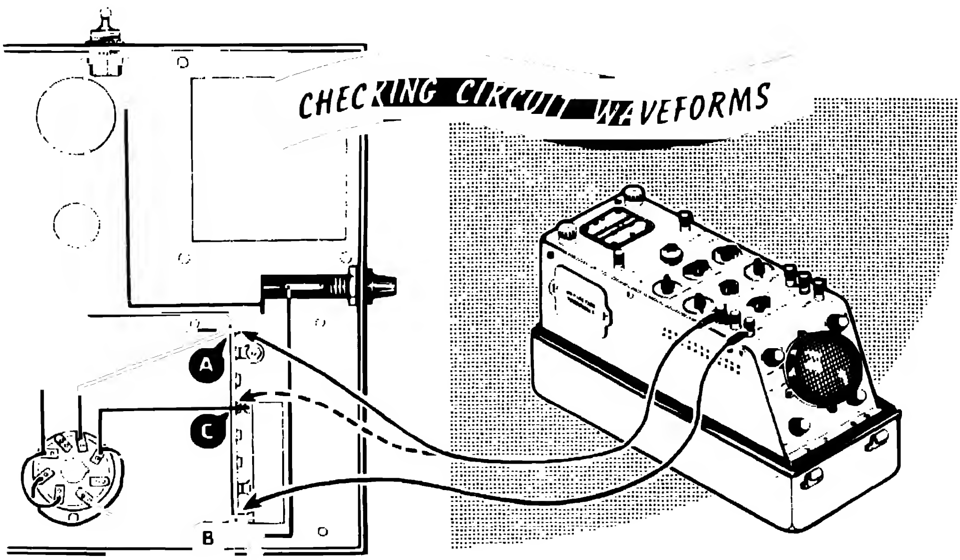
Demonstration—Testing the Vacuum Tube Rectifier Circuit

The instructor will now demonstrate the procedure for resistance and voltage testing the half-wave rectifier circuit. As a safety check before connecting a power supply to the power line, a resistance measurement should be taken across the output terminals, in this case points C and B. Since the load resistor is connected between these points, the reading obtained is about 2,000 ohms.

With power applied and the switch closed the AC and DC multimeters are used to measure the AC input and DC output voltages. The AC input is measured between points A and B and the DC output is measured between points C and B.



The set up of the oscilloscope used to check circuit wave forms is again demonstrated. For comparison of input and output wave forms, the 'scope lead connected to the GND terminal is connected at point B while the other lead connected to the AC input terminal is connected first to point A then point C.

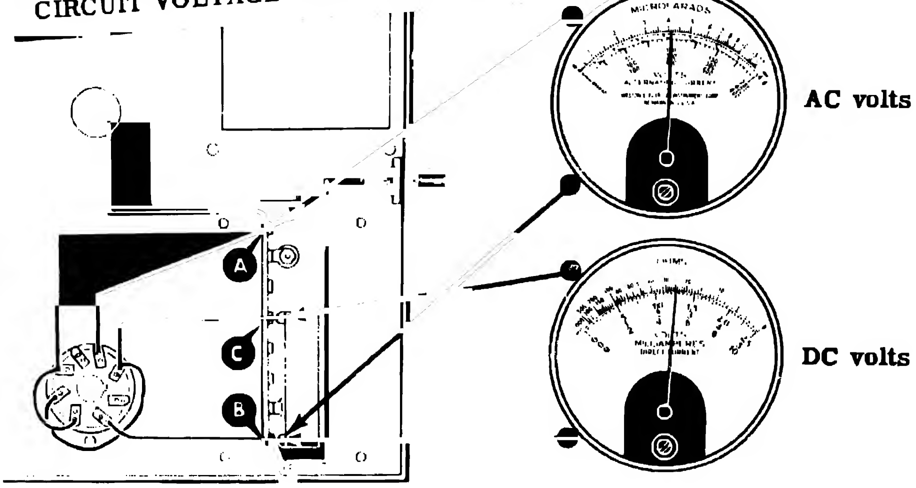


HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

Experiment—Testing the Vacuum Tube Rectifier Circuit

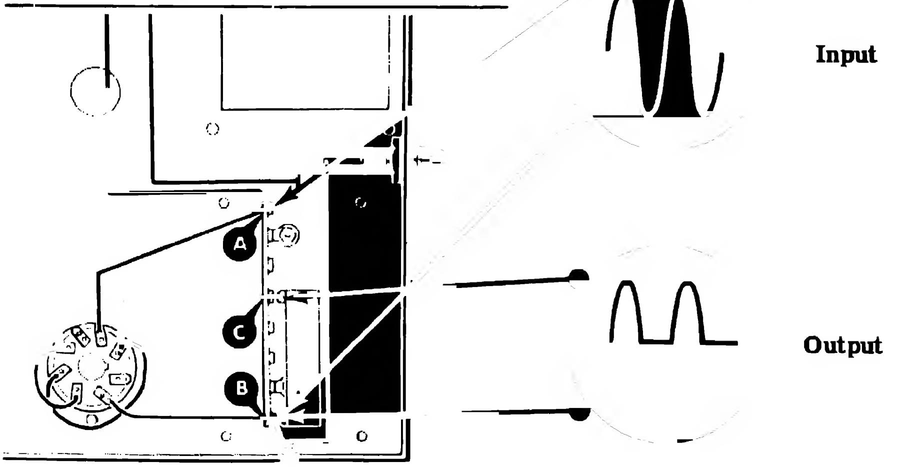
1. Apply power to the circuit and measure the AC input voltage between points A and B. Measure the DC output voltage across the load resistor, points B and C. Compare the results to those obtained when using a selenium rectifier.

VACUUM TUBE RECTIFIER CIRCUIT
CIRCUIT VOLTAGE MEASUREMENT



2. Set up the oscilloscope and observe the input and output waveforms of the rectifier circuit. When you have completed this part of the experiment remove the octal socket, the 2K resistor, and all wiring.

COMPARING THE INPUT AND OUTPUT WAVE FORMS ON THE OSCILLOSCOPE

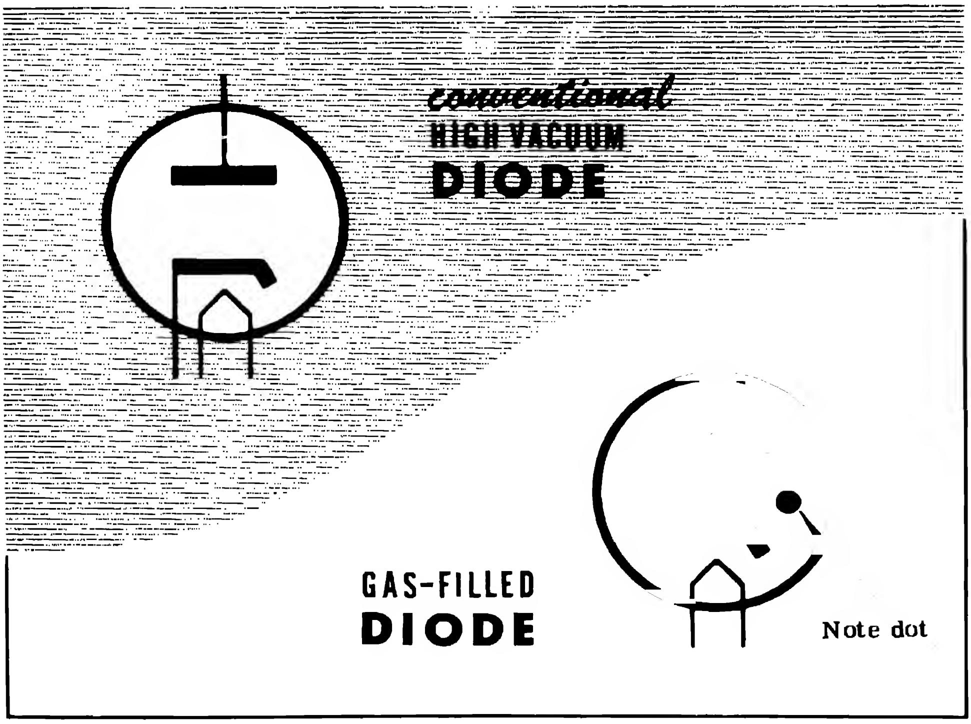


The Gas-Filled Diode

You have already learned about two types of rectifying devices—the high vacuum diode and the dry metal rectifier. You have been told that the dry metal type could be used in the same circuit as the diode and the circuit would work the same way. Now you are going to find out about a third type of rectifying device which is used in similar circuits and works in very much the same way.

Not all diodes are vacuum tubes. In some, all the air is removed from the tube and, before the tube is sealed, a small amount of chemically-inactive gas is placed in it. Then, instead of a high vacuum, the diode would have a low pressure gas in it. One common gas tube has a small quantity of mercury placed in it and, because of the low pressure around it, the mercury vaporizes. The mercury vapor acts the same way as an inert gas such as neon or argon.

The symbol for a gas tube or mercury vapor tube differs from the symbol of a high vacuum tube only by the round dot which indicates the presence of the gas. Any time you see that dot on a tube symbol, you know that the tube is of the gas-filled type.



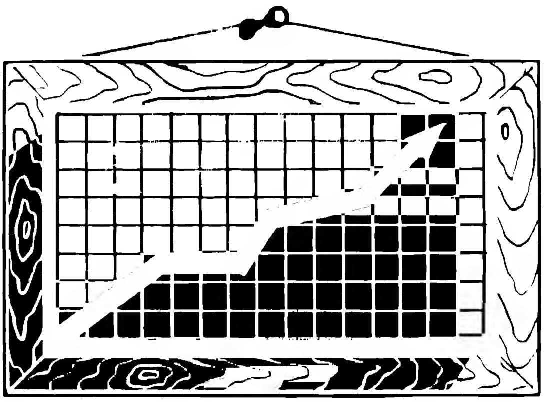
As you can see in the illustration, a gas tube has the same basic type of heater and cathode arrangement as the conventional diode. Many gas tubes have directly heated cathodes similar to the one in the type 80 high vacuum rectifier diode. Furthermore, the purpose of the cathode is the same in both types of tubes—to emit electrons.

The Gas-Filled Diode (continued)

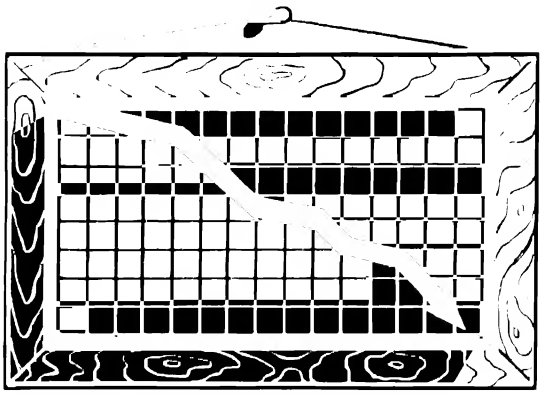
When you tested a diode, you saw that it acts just like an ordinary resistor when the tube is conducting. This is its disadvantage. Let's see why.

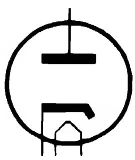
When you draw only a little current from a power supply which has a high vacuum rectifier, there is only a small voltage drop across the diode. As a result, the B+ voltage is very high. On the other hand, when a large current is taken from the power supply, the drop across the tube becomes very large and the B+ voltage drops way down. For this reason, a power supply using a high vacuum diode does not have good regulation. Regulation, is a measure of how well a power supply can maintain a constant output voltage as the load current varies from zero up to rated current. Because of its poor regulation, high vacuum rectifiers, aren't in power supplies which must deliver large load currents.

WHEN THE
LOAD CURRENT
GOES UP ....



THE
OUTPUT VOLTAGE (B+)
GOES DOWN





A POWER SUPPLY USING A
HIGH VACUUM DIODE
HAS *Poor* *Regulation*

HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

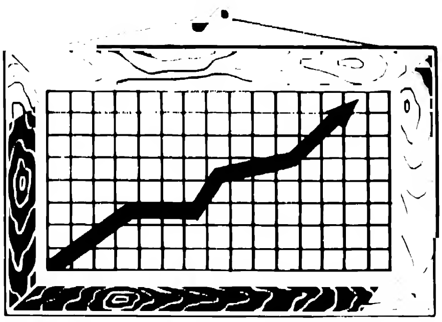
The Gas-Filled Diode (continued)

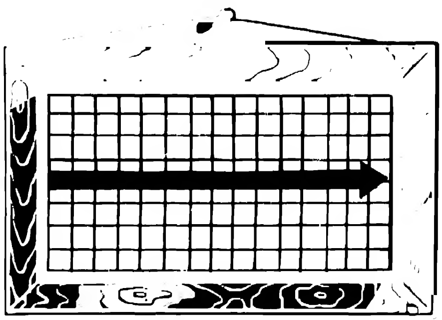
In a gas diode, electrons flow from the cathode to the plate just as in any diode. These electrons passing through the gas at fairly high speeds, knock one or more electrons out of the gas atom,leaving the atom with a + charge, and the gas is said to be ionized. The positive ions (the atoms which have had electrons knocked out of them) drift over to the cathode and pick up the electrons they lack. Some time later, another fast moving electron will knock some electrons out of the neutral atom, thus ionizing it again. In this way the gas always contains some ionized atoms.

Ionized gas has an amazing property. When a little current flows through the tube, there is a voltage drop across the tube of about 15 volts. When a lot of current passes through the tube, the voltage drop across the tube is still about 15 volts. There is an extremely small change in this voltage drop as the tube current varies over a wide range.

You can see that if the voltage across the gas tube is constant at different load currents, the B+ voltage will not change as much as it did in a power supply using a high vacuum tube. For this reason, the gas tube causes the power supply to have a better regulated output voltage than did the high vacuum tube.

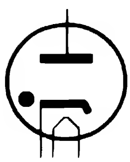
You will find gas rectifiers used on any power supply which must deliver large load currents. Because of the low drop across the gas rectifier, the power supply will be much more efficient than if a high vacuum tube had been used.





WHEN THE
LOAD
CURRENT
GOES UP ····

THE
OUTPUT
VOLTAGE (B+)
REMAINS CONSTANT

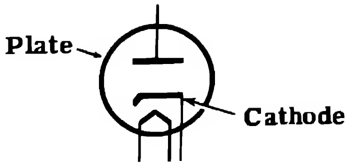


A POWER SUPPLY USING A
GAS-FILLED DIODE
HAS *Good* *Regulation*

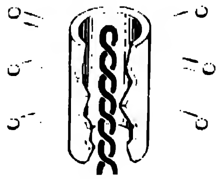
HALF-WAVE RECTIFIERS—VACUUM TUBE TYPE

Review of Vacuum Tube Rectifiers

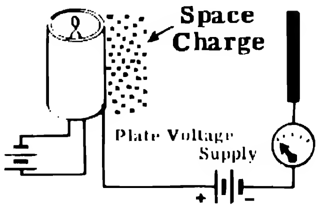
<u>DIODE VACUUM TUBE</u> — A two element vacuum tube consisting of a heated cathode and a metal plate enclosed in a glass envelope or tube from which the air has been removed.



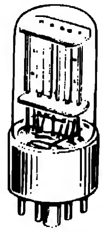
<u>ELECTRON EMISSION</u> — The action of the cathode in giving up electrons when the cathode is heated.



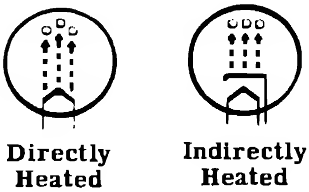
<u>SPACE CHARGE</u> — The negative charge in the area surrounding the cathode caused by the emission of electrons from the cathode.



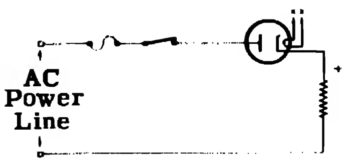
<u>RECTIFIER TUBE</u> — A vacuum tube made especially for use as a rectifier.



<u>FILAMENTS</u> — Fine wire heater used to heat the cathode in a vacuum tube. In directly heated cathode tubes, the filament and cathode are the same wire while in indirectly heated cathode tubes, the filament is called a heater and is used only to heat the cathode.



<u>BASIC VACUUM TUBE RECTIFIER CIRCUIT</u> — A diode vacuum tube connected in series with an AC voltage source to change AC to DC.

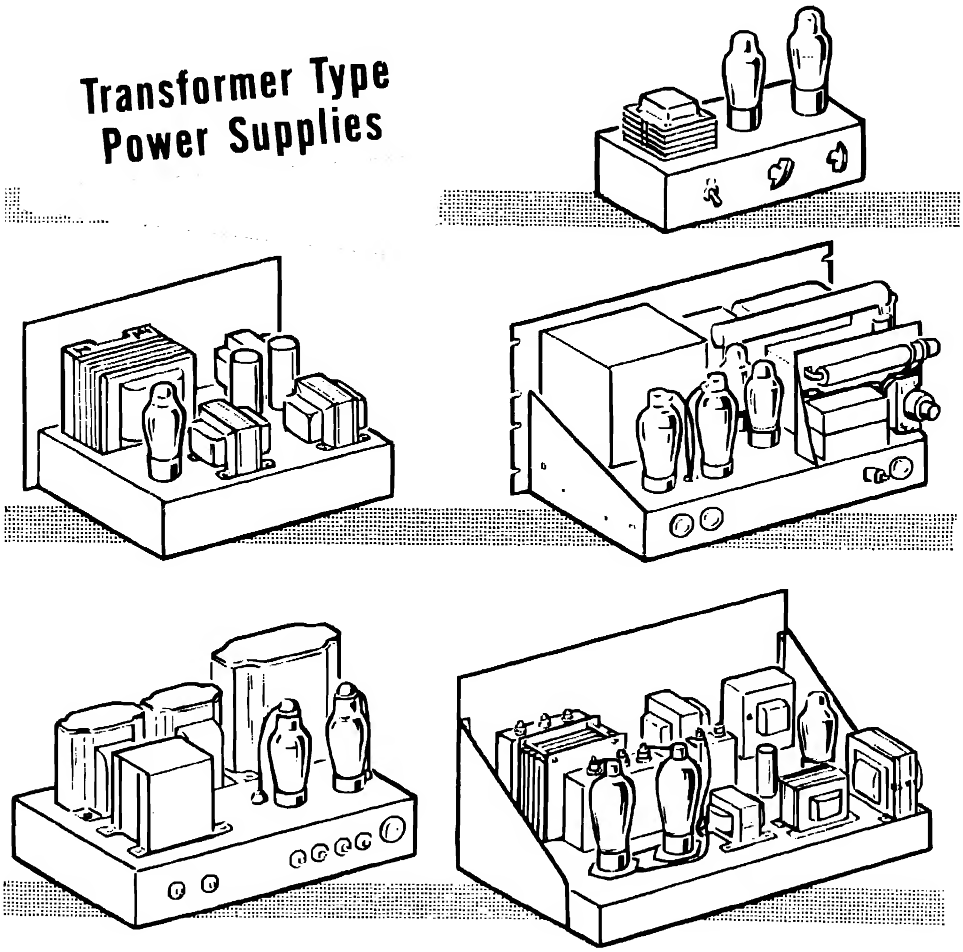


HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Transformer Type Power Supplies

The two basic rectifier circuits which you have built were used to change the 117 volt AC line voltage to DC. These rectifier circuits are often used for inexpensive power supplies when it is not necessary to isolate the rectifier circuit from the AC power line or to obtain DC voltages greater than 120 volts.

By adding a transformer to the circuit between the power line and the rectifier, the AC voltage can be increased or decreased resulting in a corresponding rise or fall of the DC output voltage. Also the output of the rectifier circuit will be completely isolated from the power line, and various filament voltages may be obtained by using additional secondary windings on the transformer. Because of the different voltages required and the need for isolating circuits in electronic equipment, most power supplies are of the transformer type. Several typical power supplies of this type are shown below.



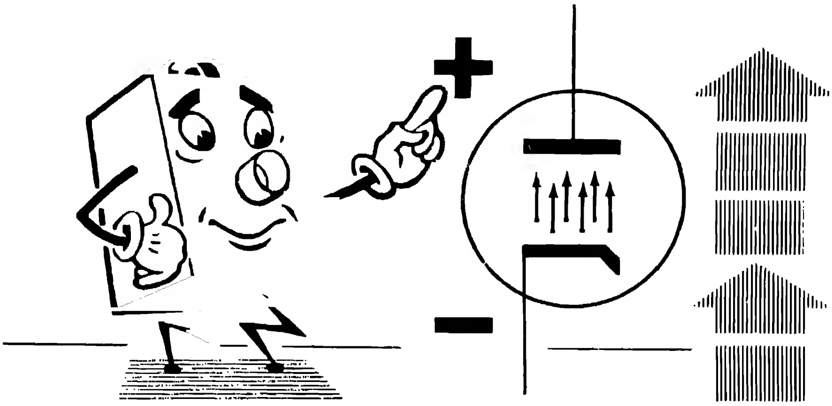
HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

The Diode in a Transformer Type Circuit

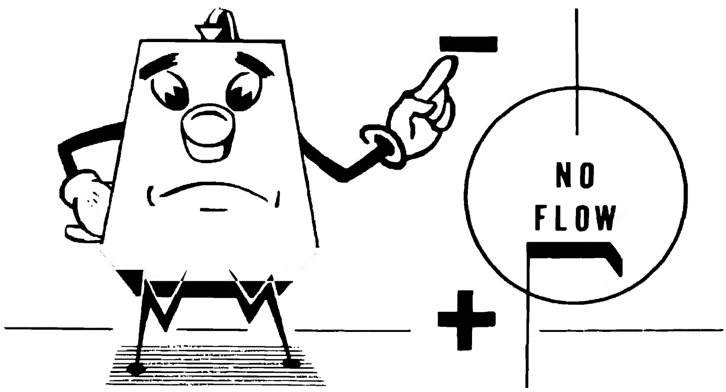
All rectifiers, including the half-wave rectifier, change an AC voltage into a pulsating DC voltage. Each rectifier accomplishes this by allowing current to flow in the circuit in only one direction, and only slight differences exist in different rectifier circuits. You are going to see how the half-wave transformer type rectifier circuit makes the change from AC to pulsating DC.

The rectifying action of this circuit depends on the operation of a diode, the rectifier tube. The theory of operation of the diode has already been covered but, in order to understand the operation of the diode in the transformer type circuit, you should review these two facts.

1. The diode allows electrons to pass through it only when its plate is positive with respect to its cathode.



2. The diode does not allow electrons to flow through it when the plate is negative with respect to the cathode.



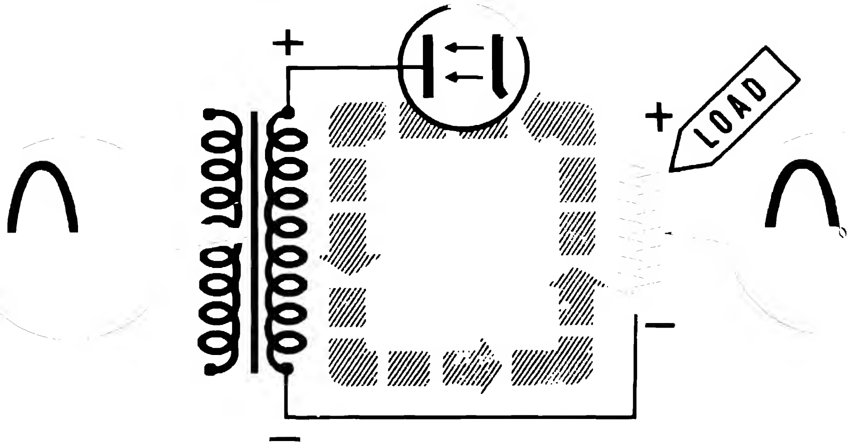
You know from your previous experiment with a diode that when the tube is connected across the 60 cycle power line the diode plate becomes positive 60 times per second and negative 60 times per second. Connecting the diode to the high voltage winding of a transformer keeps the situation exactly the same except that the voltage put on the plate is much higher, and the resulting pulsating DC is at a correspondingly higher voltage.

HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

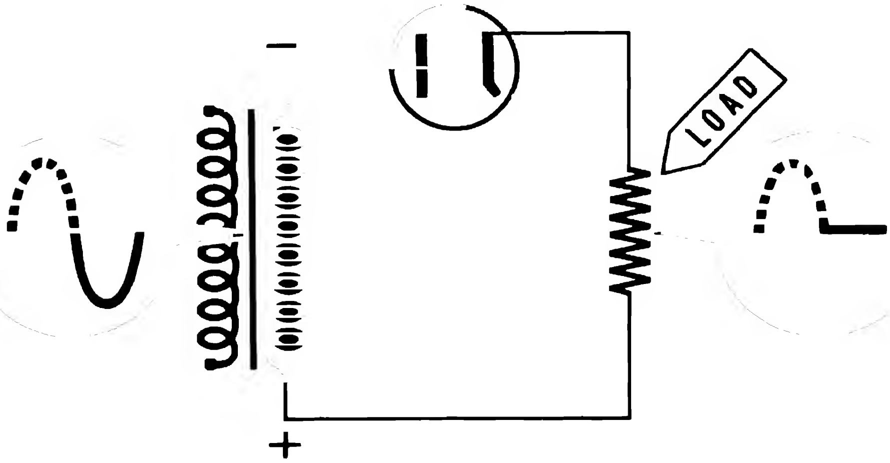
The Diode in a Transformer Type Circuit (continued)

Suppose you put the diode into a simple half-wave circuit with a transformer and see how it changes AC into DC.

When the transformer voltage makes the rectifier tube plate positive, electrons flow, and a voltage appears across the load.



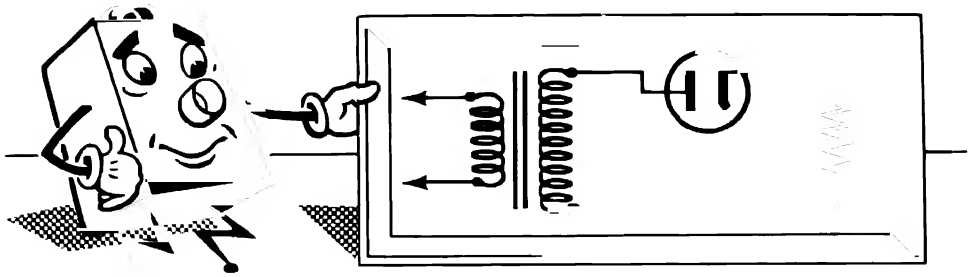
When the transformer voltage makes the rectifier tube plate negative, electrons cannot flow and, of course, no voltage can appear across the load.



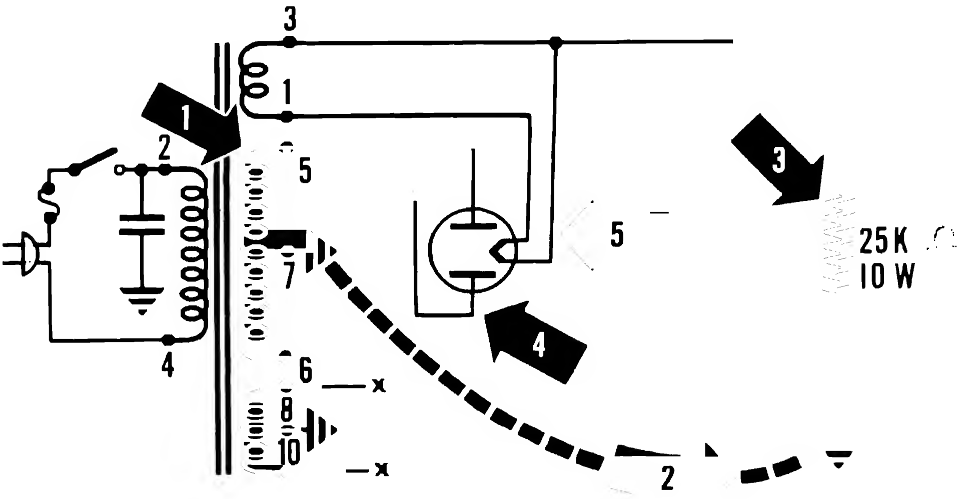
The diode rectifier tube, by allowing electrons to flow through it in only one direction (from cathode to plate), causes pulses of current to flow through the load and, therefore, causes a pulsating DC voltage to appear across the load. The AC voltage input from the transformer appears as a pulsating DC voltage across the load. Notice that the half-wave rectifier has used only the positive half of the AC input. The negative half is not used at all. You'll see these voltages on your 'scope when you build this half-wave rectifier.

HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Circuit Diagram of a Transformer Type Circuit



Compare the above schematic of the half-wave rectifier to the one below which you are going to build.



Notice the similarity between the two circuits. You can see that:

1. Only one-half of the transformer high voltage winding is used—the half from terminal 5 to terminal 7. This supplies the rectifier tube plate voltage.

2. The current path from the transformer to the load will be through the chassis (ground).

3. The load will be represented by the 25K resistor.

4. The two plates of the rectifier tube have been wired together so that the tube acts like a single diode.

5. The tube has a directly heated cathode. Therefore, the cathode is connected to the transformer filament winding—terminal 1 and terminal 3—as well as the load.

HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Experiment on the Transformer Type Circuit

You have already mounted some of the parts which are needed to build the transformer type half-wave rectifier circuit. After you have completed the building of the half-wave rectifier circuit you will find out how to test it and observe its operation.

Mount all of the major parts before wiring the circuit. In wiring, follow the step-by-step procedure outlined, and the layout illustrated on the next sheet. By this time you should know enough about wiring techniques to build this circuit without having the instructor demonstrate it for you. From now on you will be expected to build your circuits by simply following the instructions on these sheets. Do not, however, apply power to the circuit until the instructor has checked your wiring, and then demonstrated the operation of the circuit for you.

The assembly of the half-wave rectifier circuit requires that wires be twisted together. To prevent breaking of the insulation do not twist too tightly. About two or three turns to the inch is sufficient and is neater and safer than tightly twisted wires.

This Is What You Will Need

1. One chassis with terminal strip, SPST toggle switch and fuse holder mounted
2. One power transformer
3. One .001-mfd. paper capacitor
4. One four-prong tube socket
5. One power line cord with male plug attached
6. One 25K, 10-watt resistor
7. Two alligator clip leads—one red, one black
8. One OS-8A/U oscilloscope
9. One DC multimeter

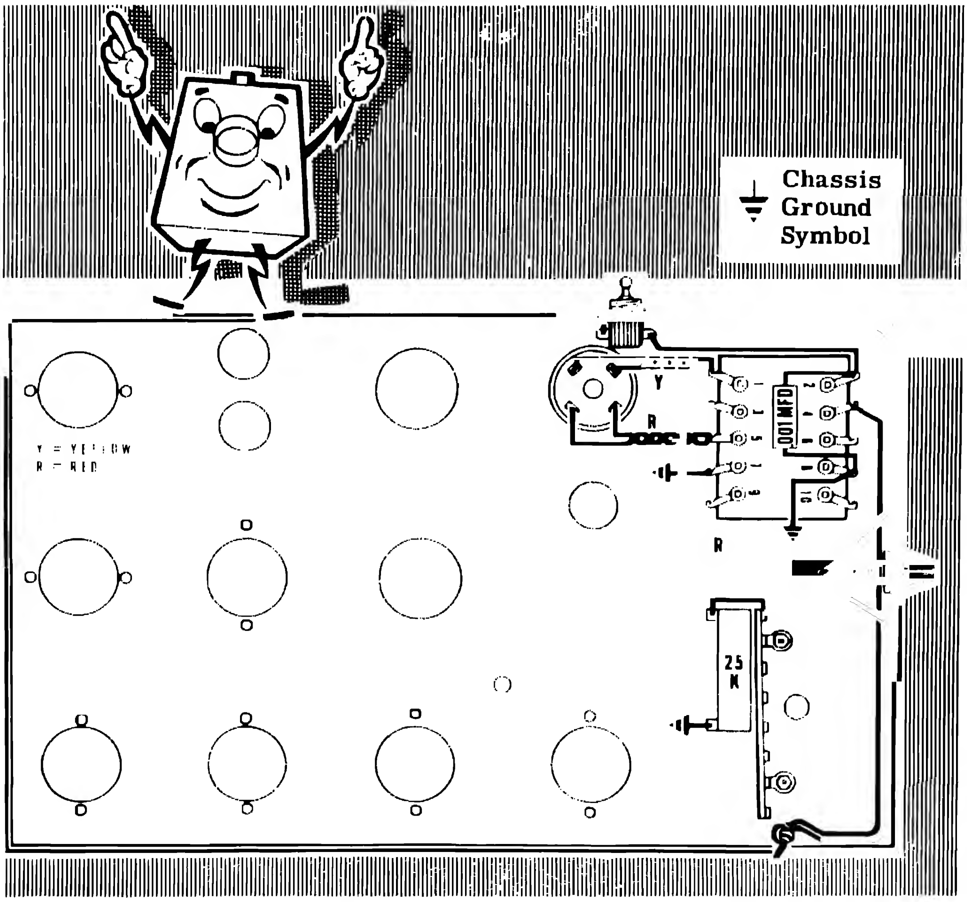
HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Experiment—Building the Transformer Type Circuit

The mounting and wiring of the parts is illustrated below. This illustration shows the underside of the chassis with all wiring completed and should be used as a guide both for mounting parts and wiring the circuit.

This type of illustration, called a pictorial view, is used with electronics circuits to show the placement of parts and their relative size as well as the wiring. It is also used to compare circuit symbols to the parts represented by the various symbols. The color coding of the wiring is that usually used in power supplies. All of the power supplies which you will build use this wiring color code but you will find that it is not always used commercially.

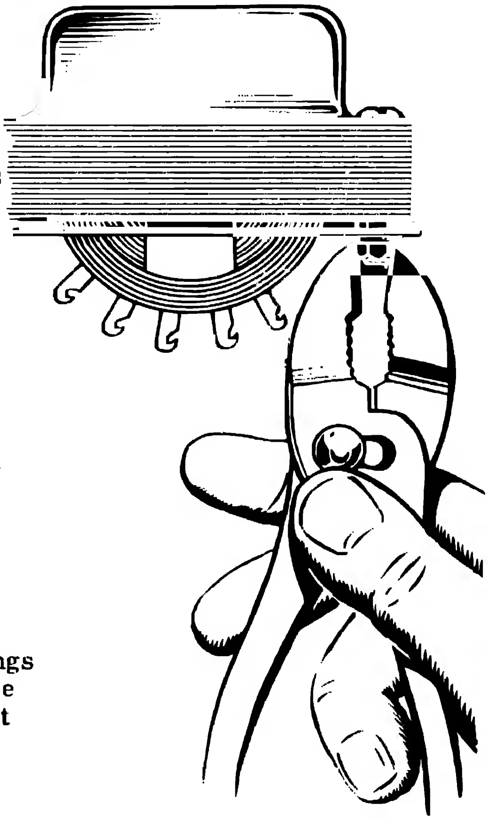
Wherever the chassis ground symbol is used it indicates that the wire is soldered to the chassis. To make good ground connections you should first tin a small area of the chassis, heating it with a soldering iron and melting solder directly onto the chassis. The wire connection should then be made to the tinned area.



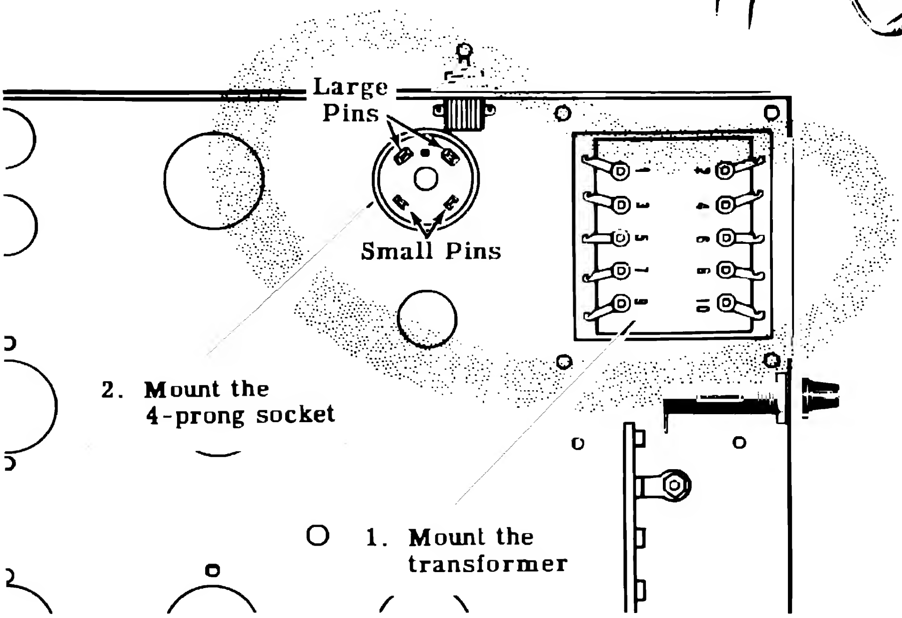
HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Experiment—Building the Transformer Type Circuit (continued)

1. Place the power transformer as shown in the layout drawings. The even-numbered terminals must face the end of the chassis as shown in the illustration of bottom view. Remove with your pliers and screwdriver the four nuts from the screws which hold the transformer coreplates together. Be careful not to move the coreplates—you may damage the transformer. Push the four transformer screws through the four mounting holes in the top of the chassis. Fasten down the transformer by slipping a lockwasher over each screw and then replacing the nuts which you removed. Tighten the mounting nuts, using your pliers and screwdriver.



2. Mount the 4-prong socket in the socket hole nearest the power transformer as illustrated in the pictorial layout of the circuit. The large prongs of the socket should be adjacent to the toggle switch and square with respect to the chassis sides.



HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Experiment—Building the Transformer Type Circuit (continued)

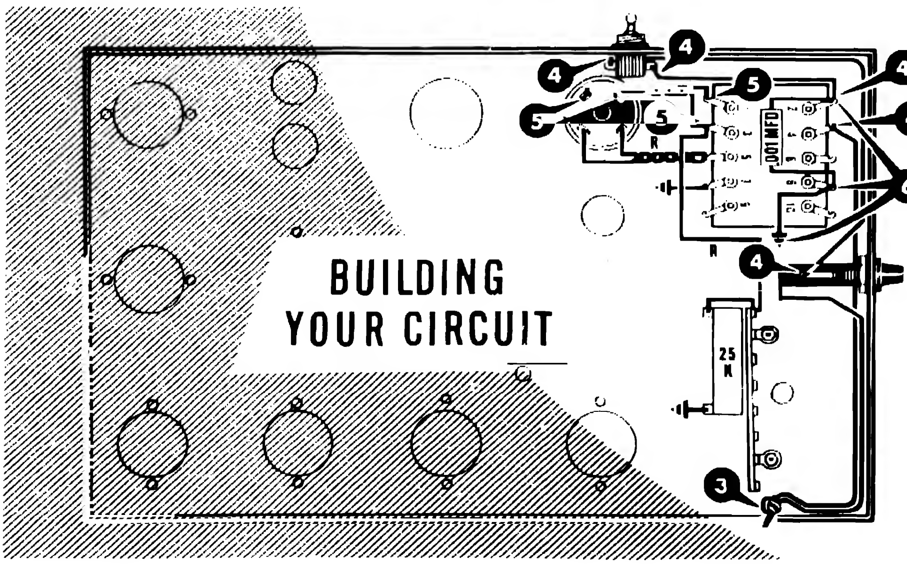
3. Pass the power supply cord through the hole in the chassis as shown in the pictorial view. See that you have enough wire to reach the toggle switch, and then put a knot in the cord just inside the chassis. This knot will take the strain off the connections you will make.

4. Connect one wire of the power supply cord to a terminal of the fuse holder. Connect the other terminal of the fuse holder to the toggle switch. Connect the other wire of the power supply cord to terminal 4 of the power transformer. Connect the other terminal of the toggle switch to terminal 2 of the power transformer, using red wire. You have just made the connections to supply power to the transformer primary through the ON-OFF switch and fuse.

5. Terminals 1 and 3 of the power transformer are the connections to the 5-volt winding. This winding will supply heater voltage for the rectifier tube which will fit into the 4-prong tube socket. Connect a twisted pair of yellow wires between terminals 1 and 3 of the transformer and pins 1 and 4 of the tube socket.

6. Connect the .001-mfd. capacitor from terminal 2 to terminal 8 of the power transformer. Be sure to connect the end marked "ground" (or banded with a black ring) to terminal 8 and connect terminal 8 to ground.

Concerning the .001 mfd. condenser—condensers are frequently used in the primary circuit of power transformers to bypass any electrical interference which might come from the power lines and sometimes to absorb any arc that might develop across the switch due to the collapsing field of the transformer when the switch is opened.



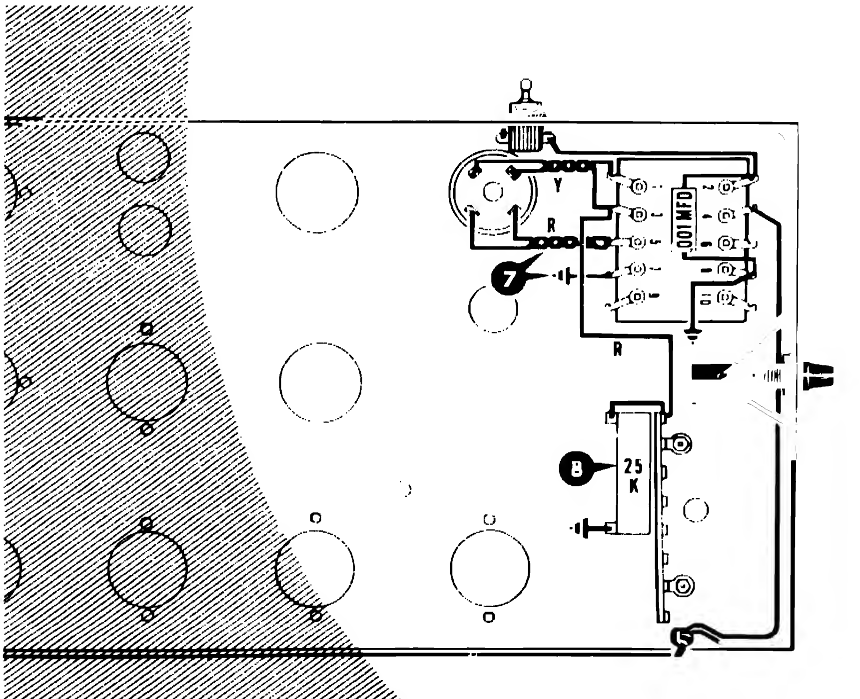
HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Experiment—Building the Transformer Type Circuit (continued)

7. To supply plate voltage to the rectifier tube, connect a twisted pair of red wires from pins 2 and 3 of the tube socket to terminal 5 of the power transformer. This connects the plates to one end of the high voltage secondary winding. Ground terminal 7, the center tap of the high voltage winding.

8. The 25K, 10-watt resistor will be part of the load for this power supply. Connect one end of the resistor to ground and the other end to the terminal strip lug nearest the power transformer. Connect a red wire from terminal 3 of the power transformer to this terminal strip lug.

9. Power transformer terminals 6, 9, and 10 are not used for this experiment and you should make certain that they are not shorted to the chassis or other parts of the circuit. Trace through the entire circuit and compare it to the circuit diagram as a check for errors in wiring. The fuse is used in the circuit to protect the various parts. Although it will not be shown in the remaining electronics circuits which you will build, it is to be mounted and wired in each power supply circuit in the same manner as for the half-wave rectifier circuit.



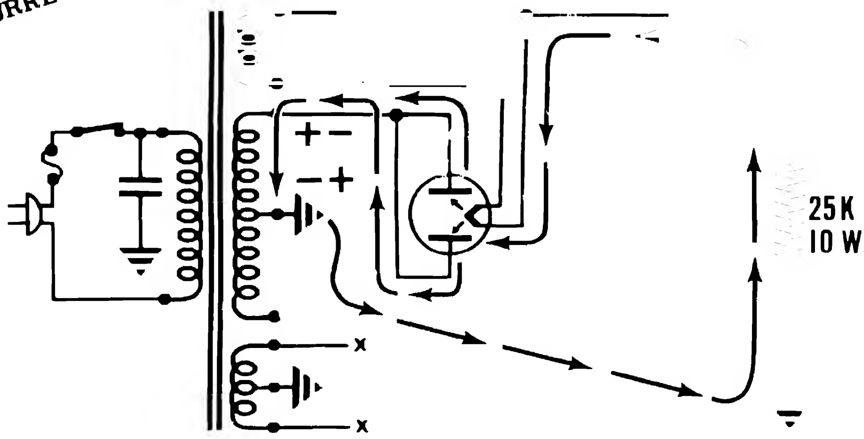
BUILDING YOUR CIRCUIT

HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Operation of the Transformer Type Circuit

The basic operation of the half-wave rectifier circuit which you have built has been described previously. In the circuit diagram illustrated the flow of current through the circuit is indicated by arrows. The + and - signs show the reversal in polarity of the transformer secondary voltage for alternate half cycles. The rectifier tube will only conduct from cathode (filament) to plate, and only when the plate is positive with respect to the cathode.

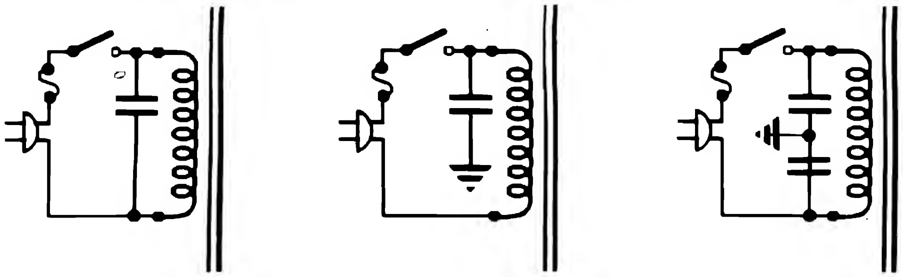
CURRENT FLOW IN A HALF-WAVE RECTIFIER CIRCUIT



Current flows for half-cycle while plates are positive.

The .001 mfd. capacitor used does not effect the circuits basic operation as a half-wave rectifier. This condenser is connected between one side of the AC power line and ground to reduce electrical interference and prevent such interference from passing through the rectifier circuit. Capacitors used for this purpose may be connected in any of the ways illustrated below.

POWER LINE FILTER CONDENSER CIRCUITS



HALF-WAVE RECTIFIER—TRANSFORMER TYPE

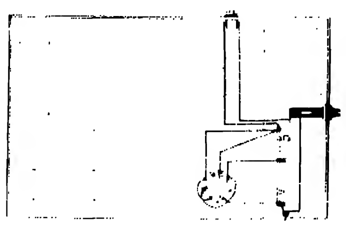
Demonstration—Safety Measures and Testing the Transformer Type Rectifier

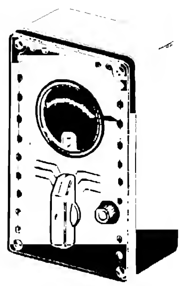
The purpose of this demonstration is to acquaint you with the safety measures to be followed in working with high voltage circuits, and to acquaint you with the procedures you will use in testing your transformer type half-wave rectifier.

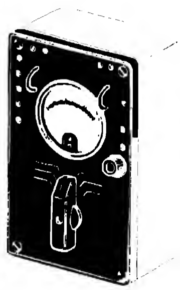
This Is What Is Needed

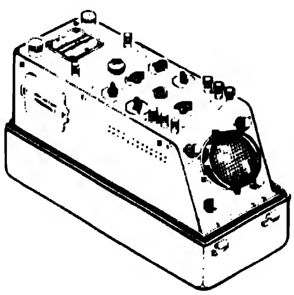
1. Chassis with half-wave rectifier circuit
2. OE multimeter—AC type
3. OE multimeter—DC type
4. OS-8A/U oscilloscope
5. Assorted test leads

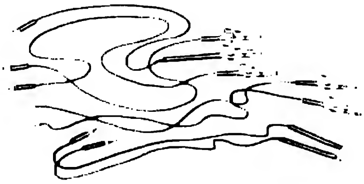
NOTE: The above items are also required for the experiment which follows.









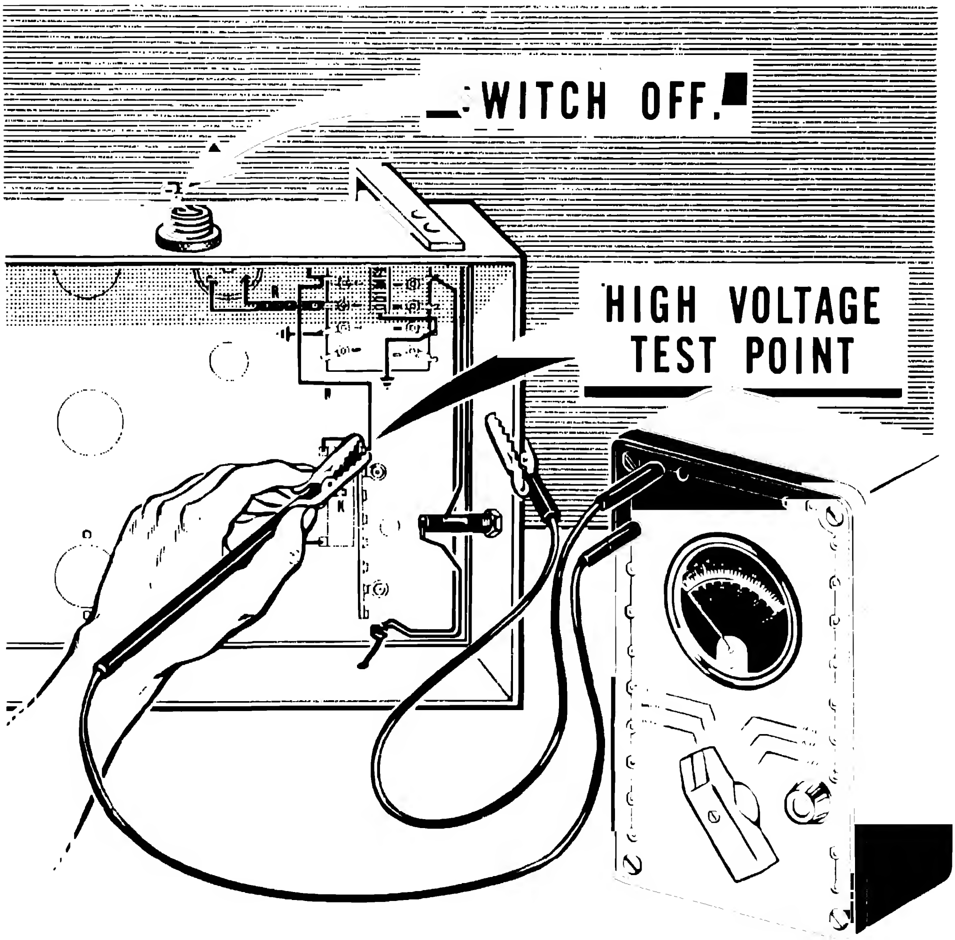


HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Demonstration—Live Circuits Safety Measures

Before you proceed one thing that you must realize is that when you work with electronics, you will be coming into contact with voltages that can be dangerous to life. Therefore, you must take the necessary precautions when checking live circuits to prevent your getting a dangerous shock. The instructor will demonstrate two procedures that you should follow to protect yourself whenever you have to check high voltage circuits using either the 'scope or the voltmeter.

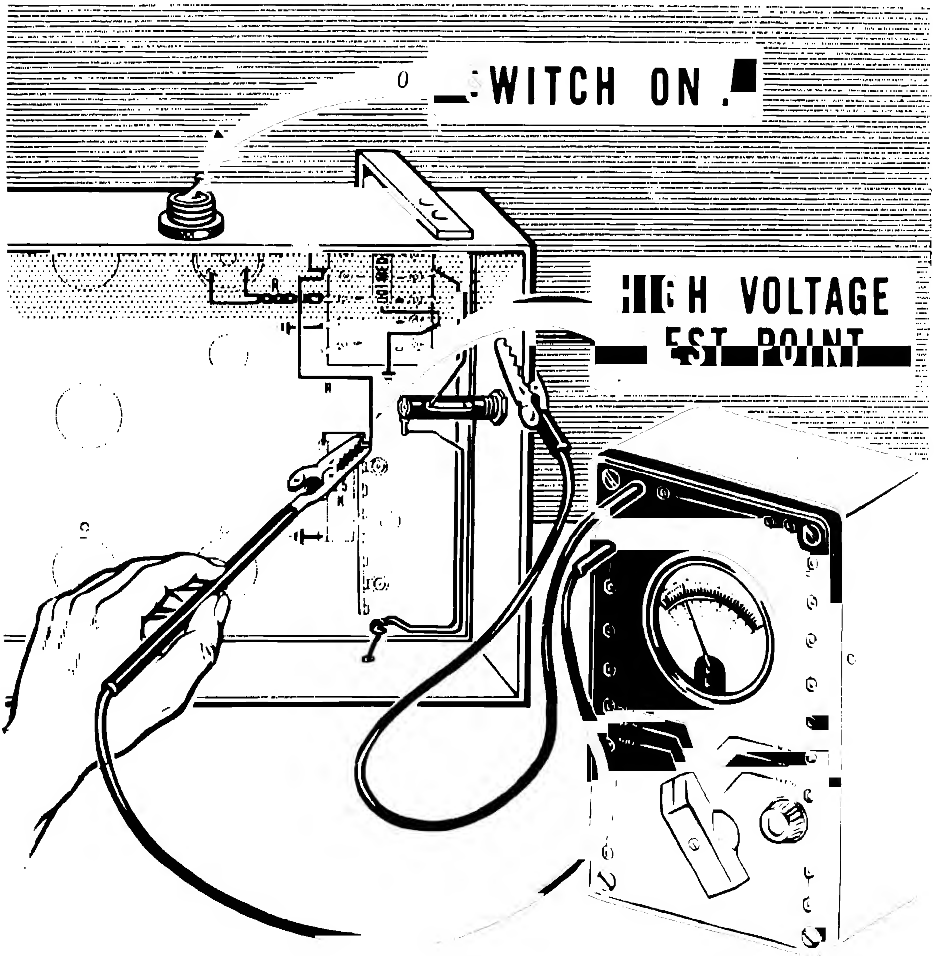
1. Turn off the circuit—then connect the test leads with alligator clips to the high voltage terminals. Turn on the circuit and, keeping your hands clear of the test leads, either read the indication on the voltmeter or observe the wave form on the 'scope. The above procedure should certainly be followed when checking any point that has a potential over 300 volts.



Demonstration—Live Circuits Safety Measures (continued)

2. When you are checking low voltage circuits below 300 volts, you can measure the voltage directly using the following procedure:

   Keep one hand behind your back or in your pocket during the entire time that you are checking the voltage or observing the wave form. With the other hand, first connect the ground lead to the chassis. Then grasp the test probe by the insulated handle and carefully apply the tip of the probe to the point in the circuit to be checked. Read the voltage or observe the wave form and then remove the probe.



KEEP FREE HAND AWAY!

Probably the best rule of all to follow is to use your head and know what you are doing at all times, and then you will never get into trouble.

HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

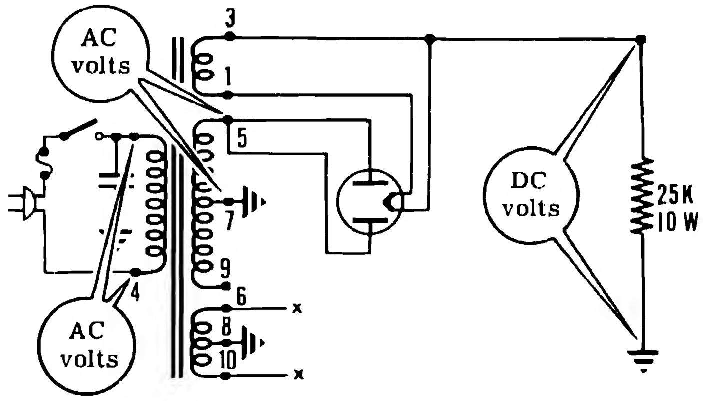
Demonstration—Testing the Transformer Type Circuit

The normal operation of a half-wave rectifier circuit can be observed either by measuring the various AC or DC voltages or by observing the circuit wave forms. The instructor will demonstrate both methods.

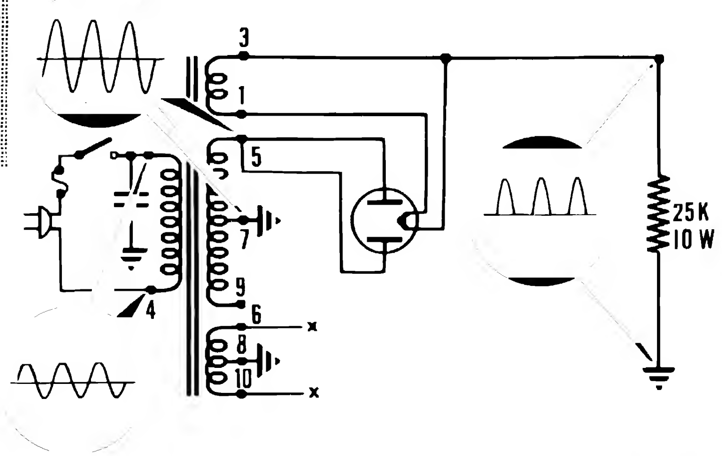
To check the circuit using voltage measurements, two meters are needed —an AC voltmeter and a DC voltmeter. The OE-12 multimeters can be used for this purpose. An AC meter is used to measure the primary and secondary voltages of the power transformer. This shows that the transformer is furnishing the desired AC input voltage to the half-wave rectifier circuit. A DC meter is used to measure the output voltage of the rectifier circuit.

Wave forms show the circuit operation better than voltage measurement since the wave form shows not only the amplitude of the voltage but also the variation in voltage. An oscilloscope such as the OS-8A/U is used to observe the wave forms of a circuit. In the half-wave rectifier circuit the wave forms of each transformer winding and of the rectifier output can be used to show normal operation.

VOLTAGE CHECK



WAVE FORM CHECK



HALF WAVE RECTIFIERS—TRANSFORMER TYPE

Experiment—Observing the Circuit Input

You are now ready to look at your half-wave rectifier. You will first examine the transformer secondary voltage which is applied to the plates of the rectifier tube.

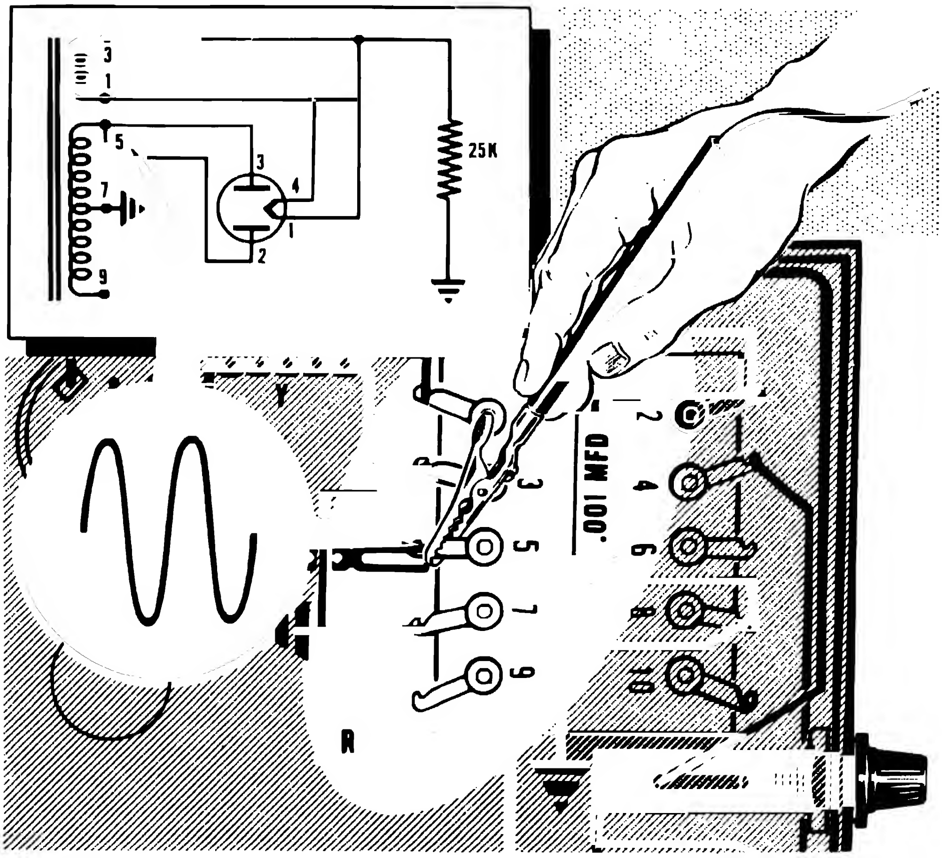
1. Attach the Y INPUT lead to transformer terminal 5.

2. Plug in the type 80 tube and turn on your power supply.

3. Adjust the SWEEP RANGE and SWEEP VERNIER controls for a two-cycle wave form.

4. Adjust the SYNC AMPLITUDE control enough to "stop" the wave form.

5. Vary the Y GAIN control until the wave form is 20 boxes, peak to peak.



The wave form you see here is the voltage across the transformer secondary. Since it is connected to the rectifier tube plate, the plate becomes positive during the positive half-cycle of the wave form. It can be called the rectifier input wave form or the transformer output wave form.

HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

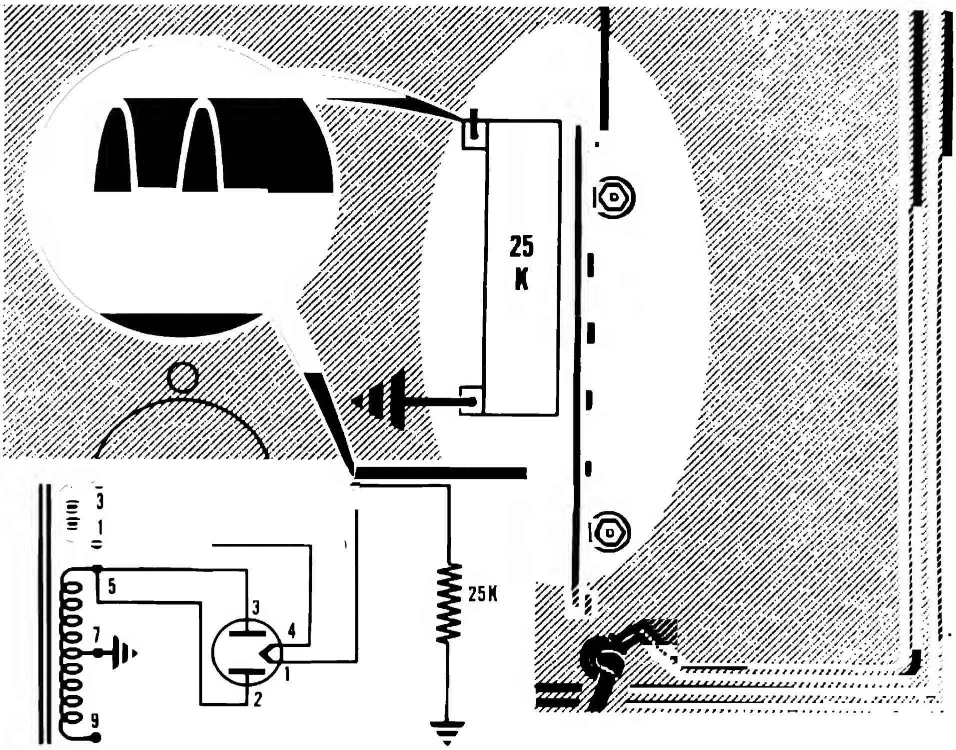
Experiment—Observing the Circuit Output

Now observe the rectifier output, without varying any of the 'scope controls.

1. Turn off your half-wave rectifier.

2. Transfer the Y INPUT lead to the end lug of the terminal strip, the one nearest the transformer.

3. Turn on your half-wave rectifier.



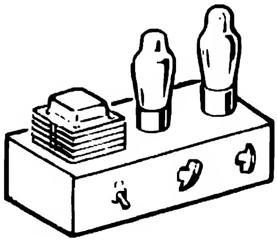
This is the pulsating DC voltage output from the rectifier. Notice that only the positive half of the AC input wave is utilized in the output. The negative half is cut off and is not used. This voltage, when filtered, can be used to operate any circuit that needs a DC voltage. Your half-wave rectifier has done its job. And you know, of course, that this pulsating DC voltage was created by the rectifier tube which allowed current to flow in only one direction through the load.

4. Now, with the DC voltmeter, measure the output of your half-wave rectifier. Set the meter on a 300-volt scale. Record this voltage for future reference. It will read about 150 volts, but be sure you know the exact voltage.

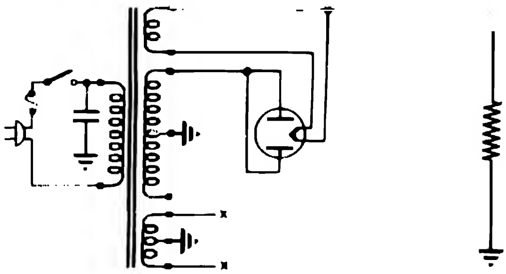
HALF-WAVE RECTIFIERS—TRANSFORMER TYPE

Review of the Half-Wave Rectifier Circuit

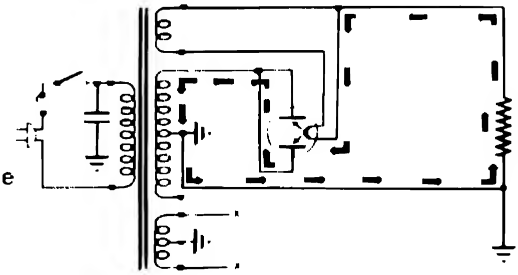
<u>TRANSFORMER TYPE POWER SUPPLY</u> — A power supply which uses a transformer to either raise or lower the AC power line voltage to obtain a desired value of DC output voltage.



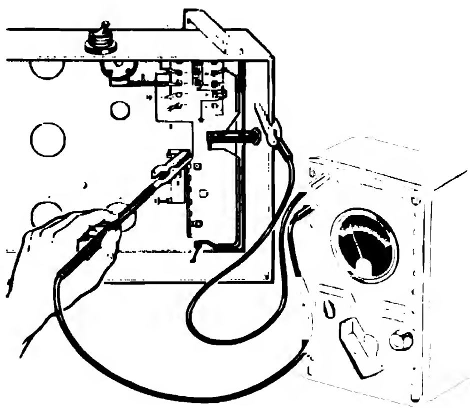
<u>HALF-WAVE RECTIFIER CIRCUIT</u> — A rectifier circuit using a single rectifier unit which changes AC to DC by allowing current to flow only in one direction. Alternate half-cycles of the AC power wave are utilized to provide a pulsating DC output. The circuit sometimes uses a transformer to increase or decrease the output voltage.



<u>CURRENT FLOW IN A HALF-WAVE RECTIFIER CIRCUIT</u> — AC is applied to the rectifier plate and current flows only during those half-cycles which are positive on the plate side of the circuit input.



<u>HIGH VOLTAGE MEASUREMENT</u> — Always use only one hand in measuring voltages or testing circuits where high voltage is present. Use a test prod which is insulated and rated for working with high voltages.



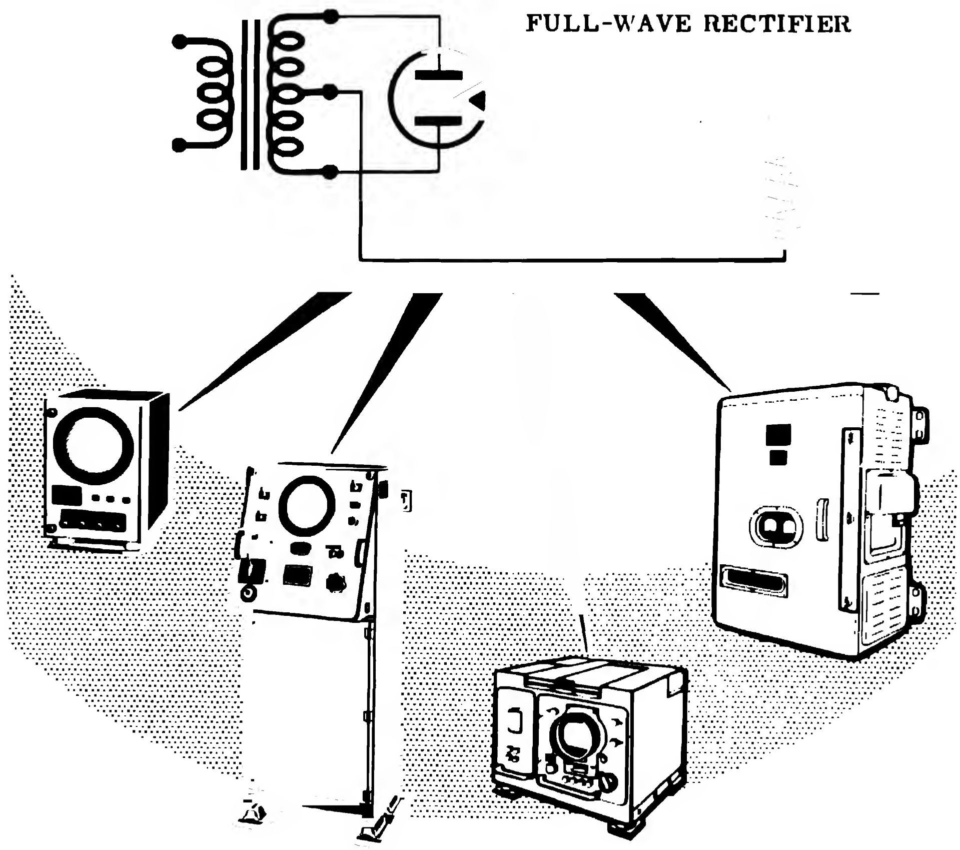
THE FULL-WAVE RECTIFIER CIRCUIT

Full-Wave Rectifiers

You have seen how the half-wave rectifier works. Now, in the following sheets you will see how the full-wave rectifier does the same job in a slightly different way. To learn how this circuit converts AC to pulsating DC, you will:

1. Learn the theory of its operations.
2. Build it.
3. Observe it with your 'scope.

You must know the full-wave rectifier because it is used in nine out of ten pieces of electronic equipment. It may be supplying any voltage from 100 volts to 5,000 volts. On any ship, any station, anywhere where electronic equipment is used, you'll find full-wave rectifiers supplying most of the power.

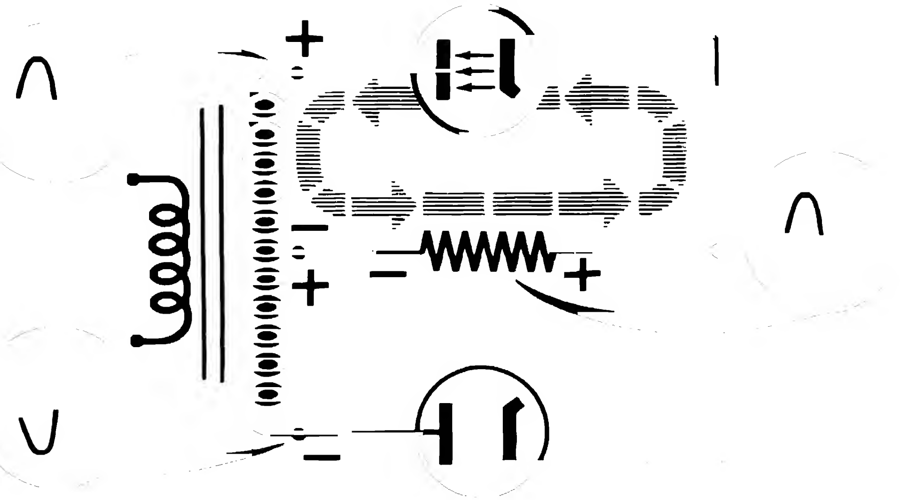


THE FULL-WAVE RECTIFIER CIRCUIT

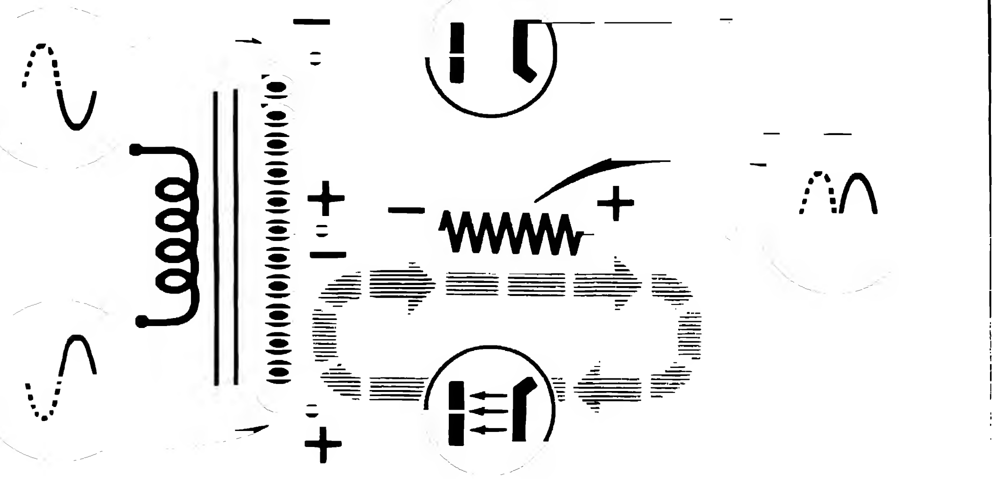
How the Full-wave Rectifier Works

In a full-wave rectifier circuit a diode rectifier tube is placed in series with each half of the transformer secondary and the load. Effectively, you have two half-wave rectifiers working into the same load.

On the first half-cycle the transformer's AC voltage makes the upper diode rectifier plate positive so that it conducts and, as a result, current flows through the load causing a pulse of voltage across the load. Notice that, while the upper diode conducts, the lower diode plate is negative with respect to its cathode so that it does not conduct.



On the second half-cycle the plate of the upper diode is negative so that it cannot conduct, whereas the plate of the lower diode is positive so that current flows through it and through the load. Since both pulses of current through the load are in the same direction, a pulsating DC voltage now appears across the load. The full-wave rectifier has changed both halves of the AC input into a pulsating DC output.



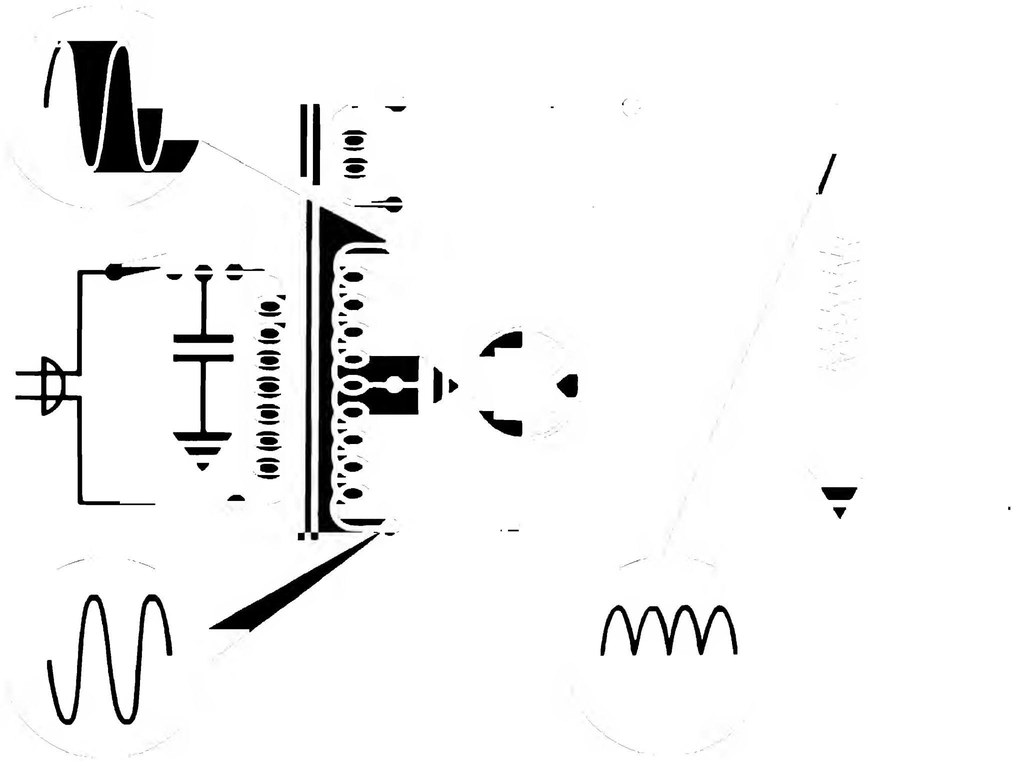
THE FULL-WAVE RECTIFIER CIRCUIT

The Full-wave Rectifier Tube

The diagram on the previous sheet shows two separate rectifier tubes being used in the full-wave rectifier circuit. Sometimes you may find this circuit used in power supplies but more frequently just one tube is used in the full-wave rectifier. If you will refer back to the diagram on the previous sheet, you will see that the filaments of the two tubes are connected together.

Since this is so, two separate rectifier tubes can be put together into one envelope so that the two plates share a common filament. The full-wave rectifier tube therefore contains two plates but only one filament. Such a tube is the 80 rectifier tube which you will use in your power supply experiment.

When a full-wave rectifier is used in a full-wave rectifier circuit, the circuit is most commonly drawn like this.



Notice that in this tube there is only one filament which supplies electrons to both plates. During one-half of the AC input cycle, one plate draws electrons from the filament and, during the other half of the cycle, the other plate draws the electrons. As in any diode, the direction of current flow inside this tube is always <u>from</u> the filament and this current flows first to one plate and then to the other. The load, which is in series with the filament, therefore has pulsating DC current flowing through it.

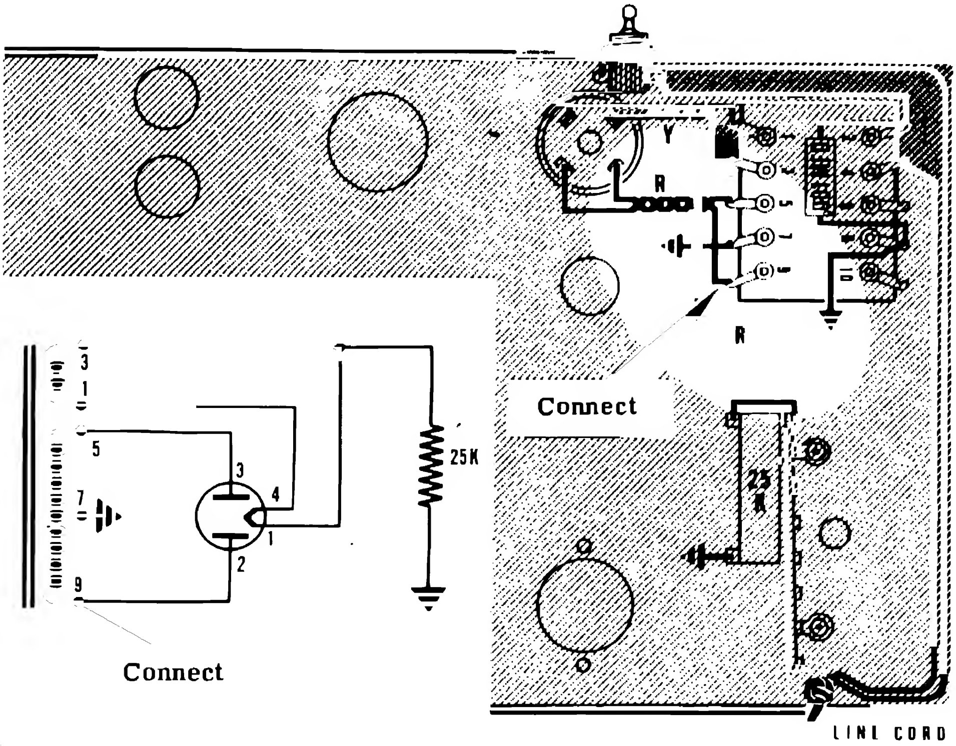
THE FULL-WAVE RECTIFIER CIRCUIT

Experiment—Building the Full-wave Rectifier

This Is What You Will Need

1. The chassis which now contains a half-wave rectifier
2. An ohmmeter and its leads
3. An "80" rectifier tube

To change your half-wave rectifier to a full-wave rectifier, disconnect the pin 2 plate lead from transformer terminal 5 and connect it to transformer terminal 9. Terminal 9 is the other end of the high voltage winding.



Changing the circuit:

Your full-wave rectifier circuit is now complete. However, before you operate it, check your work by making an ohmmeter check from tube pin 1 to ground. This reading should be 25K ohms. If it is, your full-wave rectifier is safe for operation. If not, go back over your work.

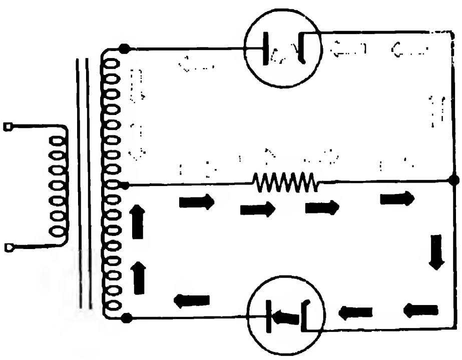
THE FULL-WAVE RECTIFIER CIRCUIT

Current Flow in the Full-wave Rectifier Circuits

The illustration below compares the operation of the full-wave rectifier circuit you have built to that of a basic full-wave rectifier.

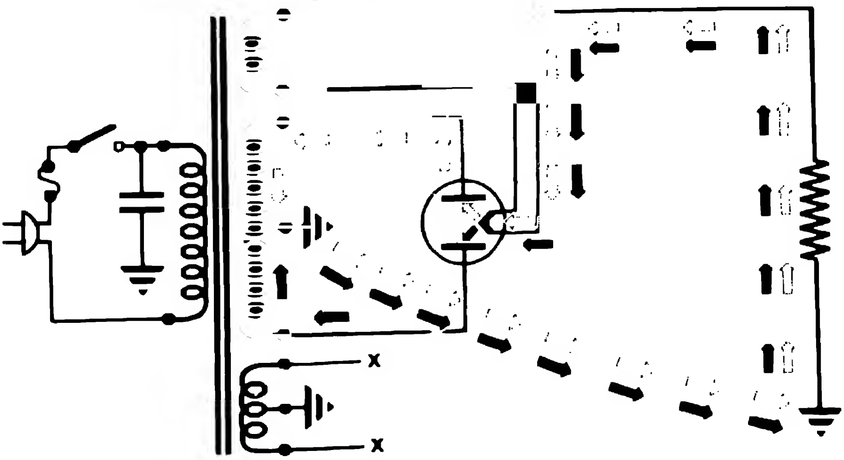
In the basic circuit illustrated, plates 1 and 2 of the rectifier tube are connected to opposite ends of the transformer winding so that there is always a 180 degree phase difference between the voltages applied to the two plates. Current flows only to that plate which is positive so that current flows from a common cathode to each plate on alternate half cycles. Since the load resistor is connected between the cathode and the transformer secondary winding centertap, the current flow in the load resistor is in the same direction for both half cycles.

In the basic full-wave rectifier circuit two cathodes are used but since they are connected together a single common cathode can be used instead in a typical circuit. Also in the basic circuit one end of the load resistor connects directly to the transformer secondary winding centertap and no ground connection is used. This connection can be made by grounding the centertap and one end of the load resistor to different points on the chassis.



BASIC FULL-WAVE RECTIFIER CIRCUIT

TYPICAL COMPLETE FULL-WAVE RECTIFIER CIRCUIT



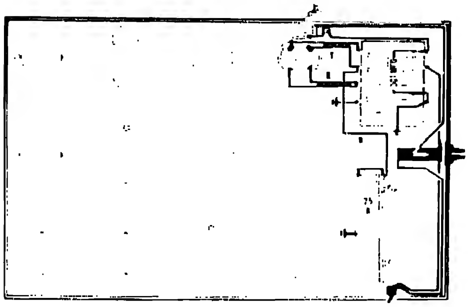
THE FULL-WAVE RECTIFIER CIRCUIT

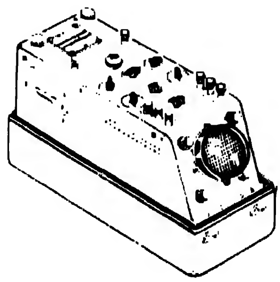
Demonstration—Full-Wave Rectifier Operation

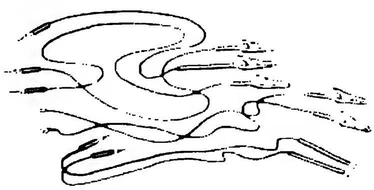
In your work with half-wave rectifiers you saw for yourself that one half cycle of the AC voltage input could be used to give you a pulsating DC output. This demonstration will show you that both the positive and the negative half cycles of the AC voltage input can be used to give you a pulsating DC output with twice as many DC pulses as put out by a half-wave rectifier.

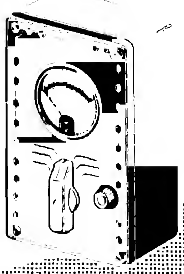
This IS WHAT IS NEEDED

1. Full-wave rectifier circuit complete with tubes
2. OS-8A/U oscilloscope
3. DC multimeter with test leads
4. Assorted test leads





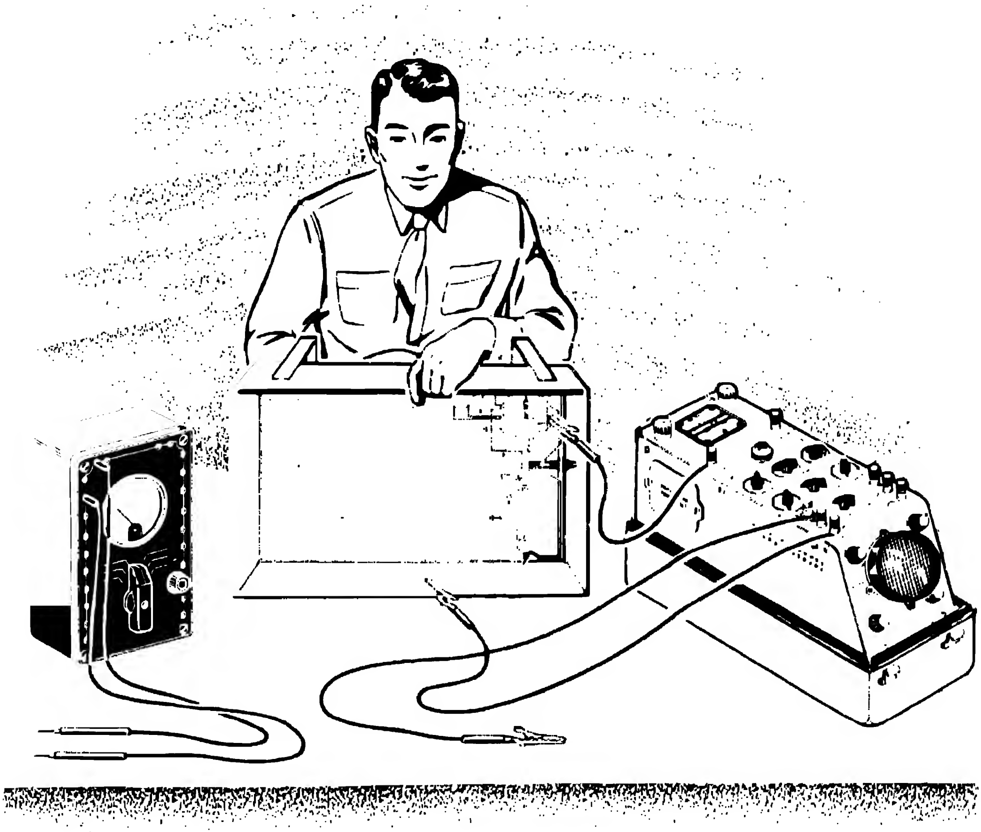




Note that the above listed parts are the same as required for the experiment which follows this demonstration.

Demonstration—Full-Wave Rectifier Operation (continued)

Before the operation of the full-wave rectifier can be observed the equipment must be set up as shown here:



As the instructor sets up his equipment in this manner, you should set up your equipment in the same way so that it will be ready for the experiment. The instructor goes through the following steps in getting ready for the demonstration:

1. He connects a lead from the 'scope ground connection to the chassis.

2. He connects a lead with a test prod to the 'scope Y INPUT binding post.

3. He connects a lead from the 'scope EXT SYNC binding post to transformer terminal 6.

4. He switches the 'scope SYNC SELECTOR switch to EXT.

5. He puts the 'scope into operation in the usual manner and turns on the full-wave rectifier power switch.

THE FULL-WAVE RECTIFIER CIRCUIT

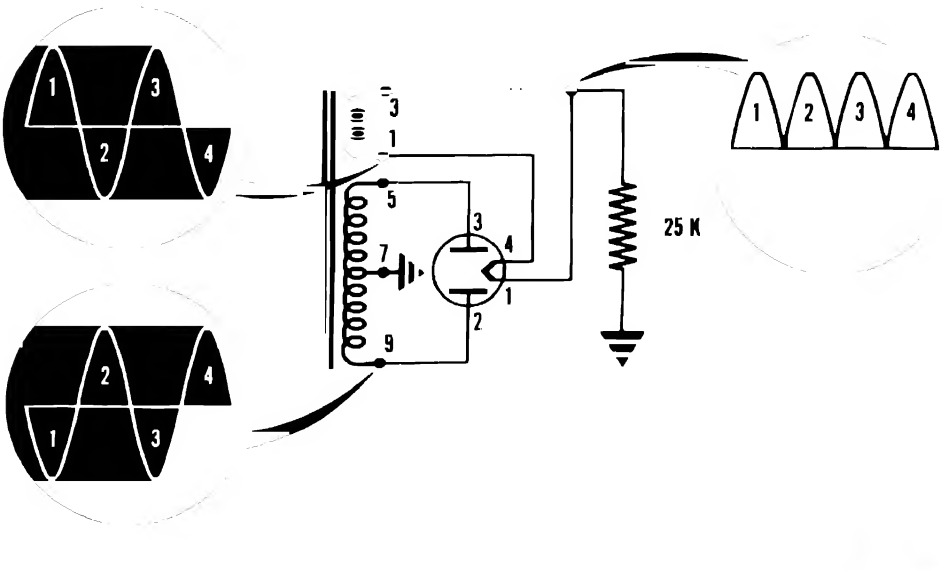
Demonstration—Full-Wave Rectifier Operation (continued)

The first part of the demonstration involves the examination of the transformer secondary wave form. The instructor connects the 'scope first to one side of the transformer secondary (terminal 5) and then to the other side of the transformer secondary (terminal 9). Because the 'scope is switched to EXT SYNC, you can see that the voltage outputs on the two transformer secondary terminals are 180 degrees out of phase with each other. This means that when one side of the secondary is positive the other side of the secondary is negative as shown in the illustration below.

In the next part of the demonstration the instructor connects the 'scope first to one plate of the rectifier tube (pin 3) and then to the other plate of the rectifier tube (pin 2). You see that the AC voltages present at these plates are of the same amplitude as on the transformer secondary and are also 180 degrees out of phase. Therefore each rectifier plate becomes alternately positive and negative; and when one plate is positive the other is negative.

In the next part of the demonstration the instructor connects the 'scope to the rectifier tube filament (pin 3) which is the output of the rectifier circuit. You can easily see that there is a pulsating DC voltage at this point and that all pulsations are in the same direction. The instruction shows you that for each half cycle of the AC voltage input—whether positive or negative—there is a positive pulse of DC voltage appearing at the rectifier tube filament as shown below.

The demonstration concludes with a measurement of the AC and DC voltages at the points examined with the oscilloscope. The instructor shows you that the DC voltage at the rectifier output is lower than the AC voltage on either plate. Aside from meter errors, the main cause of this is the voltage across the vacuum between the filament and each of the plates.

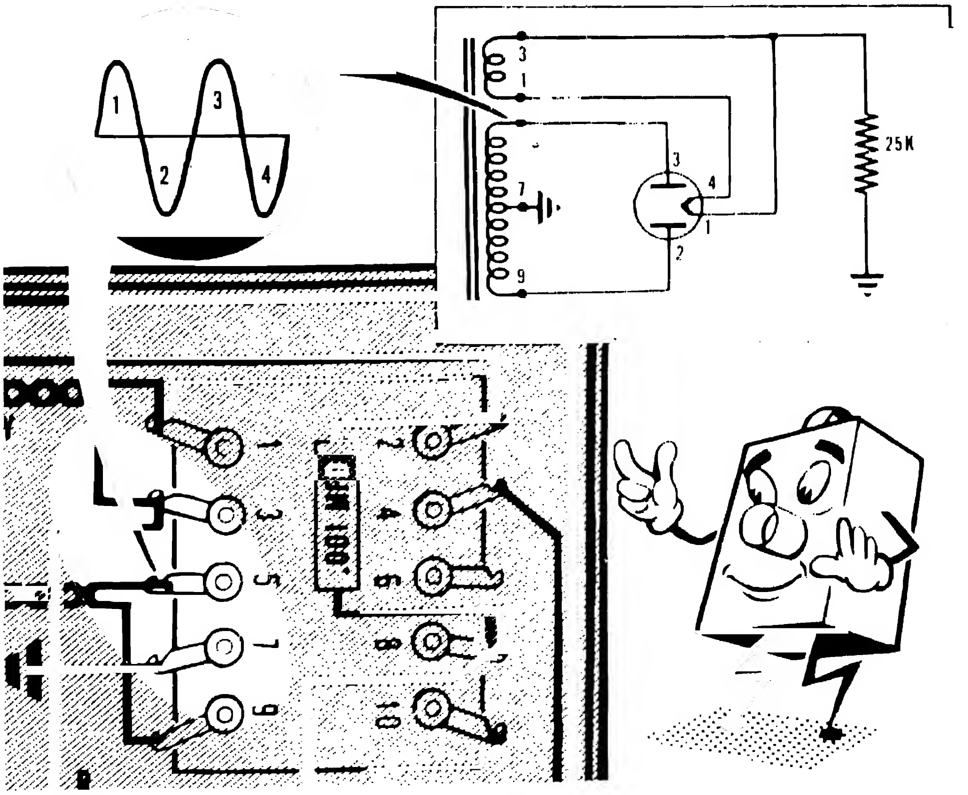


THE FULL-WAVE RECTIFIER CIRCUIT

Experiment—Observing the Full-wave Rectifier Input

You are now ready to look at your full-wave rectifier. You will first examine the AC voltage which goes right to the upper plate of the rectifier tube.

1. Attach the Y INPUT lead to transformer terminal 5.
2. Turn on your power supply.
3. Adjust the SWEEP RANGE and SWEEP VERNIER controls for a two-cycle wave form.
4. Adjust the SYNC AMPLITUDE control to "stop" the wave form.
5. Vary the Y GAIN control until the wave form is 20 boxes, peak to peak. After the control is set, do not change it again during the experiment.



This wave form is the AC voltage which is applied to the upper plate of the full-wave rectifier tube. Observe that it swings first positive, then negative. The top half of the diode rectifier tube will therefore conduct only when its plate is positive, which will be during the first and third half-cycles of the AC voltage applied to its plate.

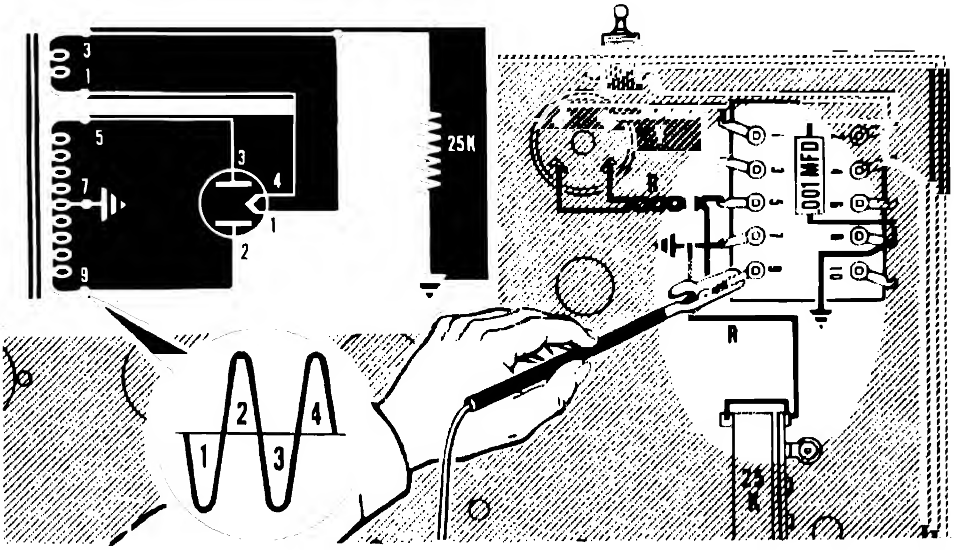
THE FULL-WAVE RECTIFIER CIRCUIT

Experiment—Observing the Full-wave Rectifier Input (continued)

You are now going to examine the AC voltage which goes right to the lower plate of the rectifier tube.

Without varying any of the 'scope controls:

1. Turn off your full-wave rectifier.
2. Transfer the Y INPUT lead to transformer terminal 9.
3. Turn on the power



Now you are observing the AC voltage input to the lower plate of the rectifier tube. Notice that it swings first negative, then positive. It is 180 degrees out of phase with the other plate voltage. You know that this is correct because both ends of a transformer winding have the opposite voltage polarity at any instant. The lower half of the diode rectifier tube will conduct only when its plate is positive, which will be during the second and fourth half-cycles of the AC voltage applied to its plate. The upper and lower diodes, therefore, conduct during alternate halves of the AC input wave form.

You may have wondered why you are using external sync instead of internal sync. You do so in order to see phase relationships between various parts of a circuit. In this observation you observed a phase relationship between the top and bottom half of the transformer. When you use internal sync, you don't get to see phase relationships. All wave forms are seen with the positive alternation appearing first. To demonstrate this, throw the SYNC SELECTOR switch to INT. Notice that the wave form you now see is in phase with the one at the other end of the transformer secondary winding.

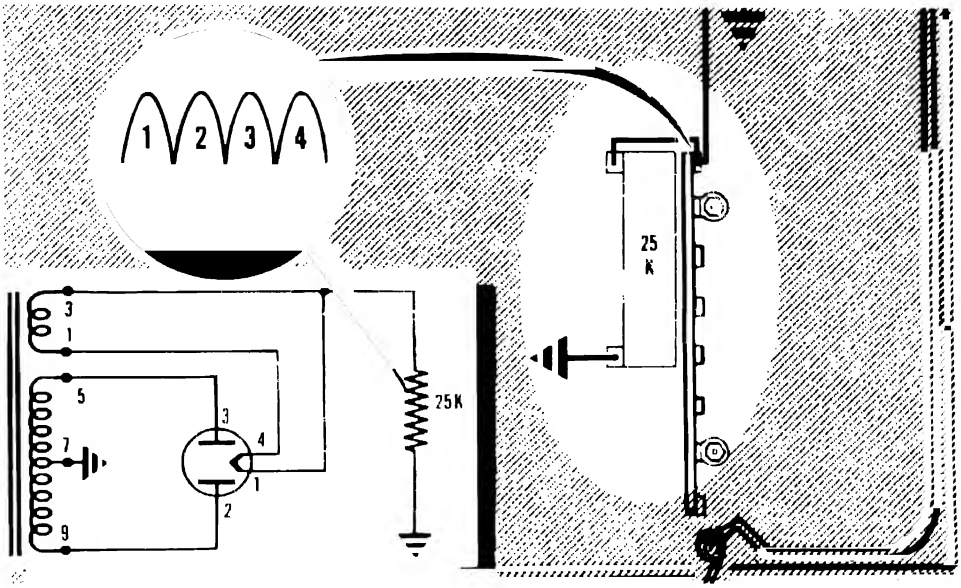
Before observing the full-wave rectifier output, throw the SYNC SELECTOR switch back to EXT.

THE FULL-WAVE RECTIFIER CIRCUIT

Experiment—Observing the Full-wave Rectifier Output

You are now going to observe the full-wave rectifier output without varying any of the 'scope controls.

1. Turn off your full-wave rectifier.
2. Transfer the Y INPUT lead to the ungrounded end of the 25K load resistor.
3. Turn on the power.



Now you are observing the pulsating DC voltage output of your full-wave rectifier circuit. Notice that alternations one and three are supplied by the upper diode, and alternations two and four are supplied by the lower diode. This wave form is called a full-wave pulsating DC wave form. Here, both halves of the AC input are utilized in the output. The full-wave rectifier has simply taken the negative alternations of the AC input and inverted them so that they have become positive alternations across the output.

Now, with your DC voltmeter, measure and record the output voltage of your full-wave rectifier. Use a 500-volt scale. Observe that this output is about 300 volts. Because the full-wave has twice as many half cycles as the half-wave output, its voltage is about twice as large. It is also a purer form of DC than the half-wave output which makes it much easier to filter.

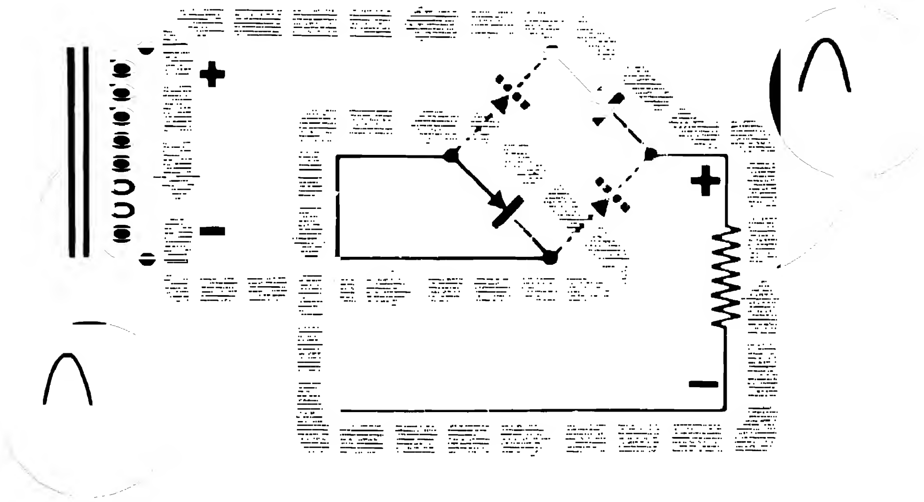
Before going further, review your knowledge of the full-wave rectifier. See if you can draw the circuit and its wave forms without help.

THE FULL-WAVE RECTIFIER CIRCUIT

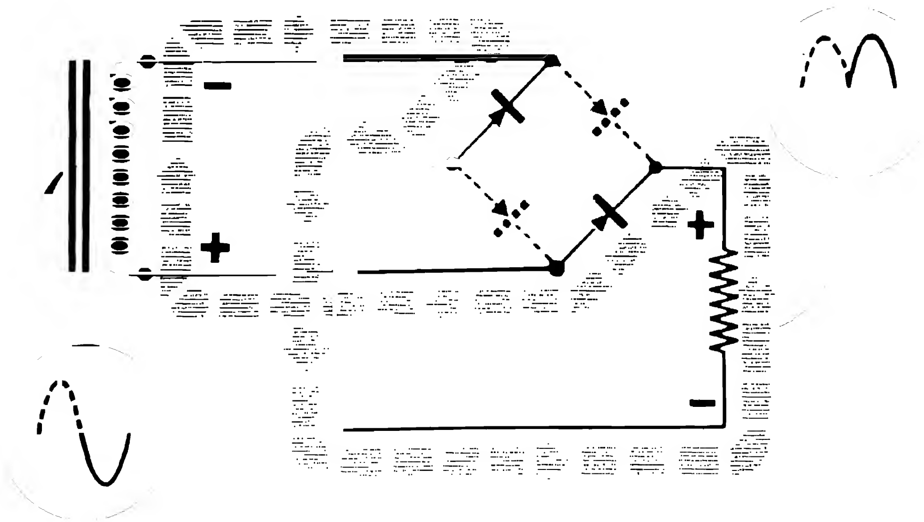
The Bridge Rectifier Circuit

The bridge rectifier, just like the other rectifiers you have studied, changes AC voltage to DC voltage. Here's how it does it!

Four dry metal rectifiers are hooked together with the AC input and the load as shown. As the AC voltage input swings positive, current flows from one side of the input through one dry metal rectifier, through the load, and then through another dry metal rectifier back to the other side of the input.



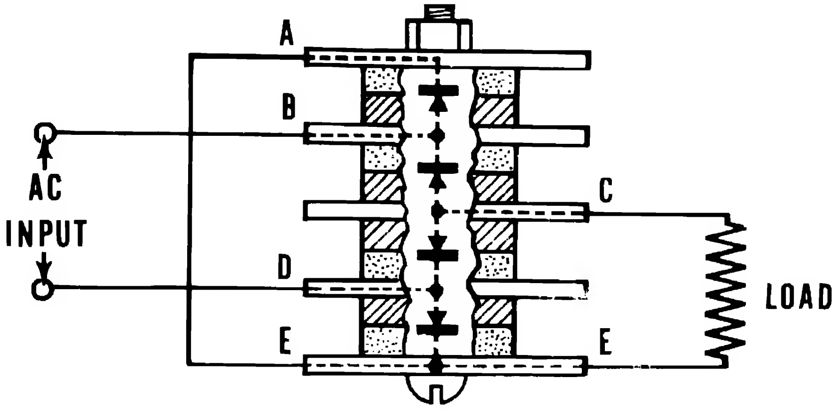
Then, when the AC voltage input swings negative, current flows through the other pair of dry metal rectifiers and the load. Notice that the current flow through the load is in the same direction during both half-cycles of the input wave. Therefore, the voltage developed across the load is pulsating DC which can, of course, be filtered just as any other pulsating DC output from a rectifier circuit.



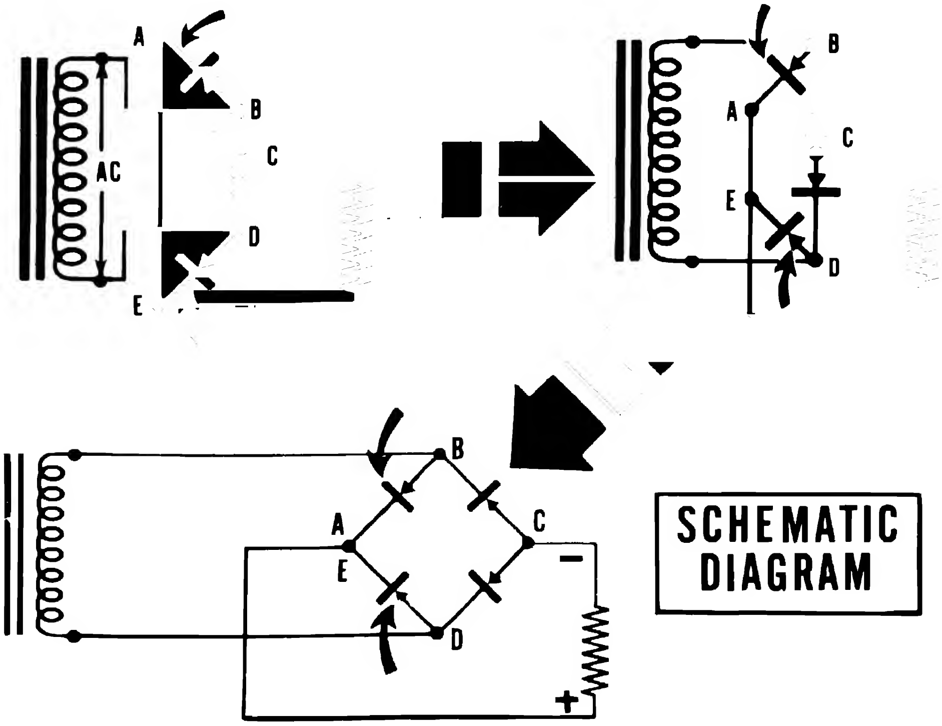
THE FULL-WAVE RECTIFIER CIRCUIT

The Bridge Rectifier Circuit (continued)

In actual practice the four dry metal rectifier units used in the bridge rectifier circuit are joined together in one physical unit and are connected externally into the bridge rectifier circuit.



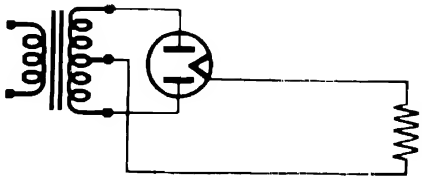
To get from the pictorial to the schematic diagram, just imagine the two end units being rotated around as shown below. Before you continue, make sure you understand the relationship between the physical unit and the schematic. When you have the basic understanding of a bridge rectifier, you will be ready to hook one up and to watch it work.



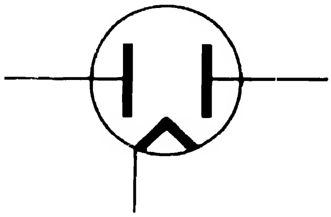
THE FULL-WAVE RECTIFIER CIRCUIT

Review of the Full-Wave Rectifier Circuit

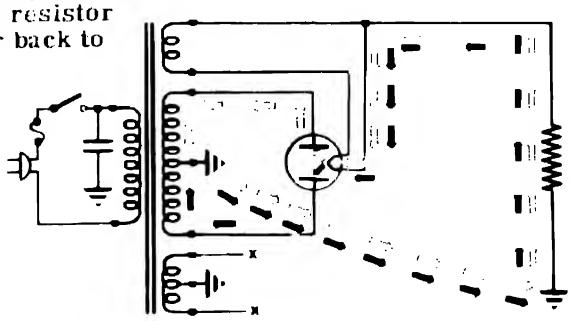
FULL-WAVE RECTIFIER CIRCUIT - A rectifier circuit which utilizes both cycles of the applied AC voltage to obtain pulsating DC. A center-tapped transformer secondary winding is used with two diodes rectifying alternate half cycles of the voltage, causing pulses of current to flow in the same direction through a load resistor for each half cycle of applied AC.



FULL-WAVE RECTIFIER TUBE - A vacuum tube consisting of two specially designed diodes and a common cathode in the same glass envelope. Both direct and indirectly heated cathodes are used depending on the requirements of the rectifier circuit.



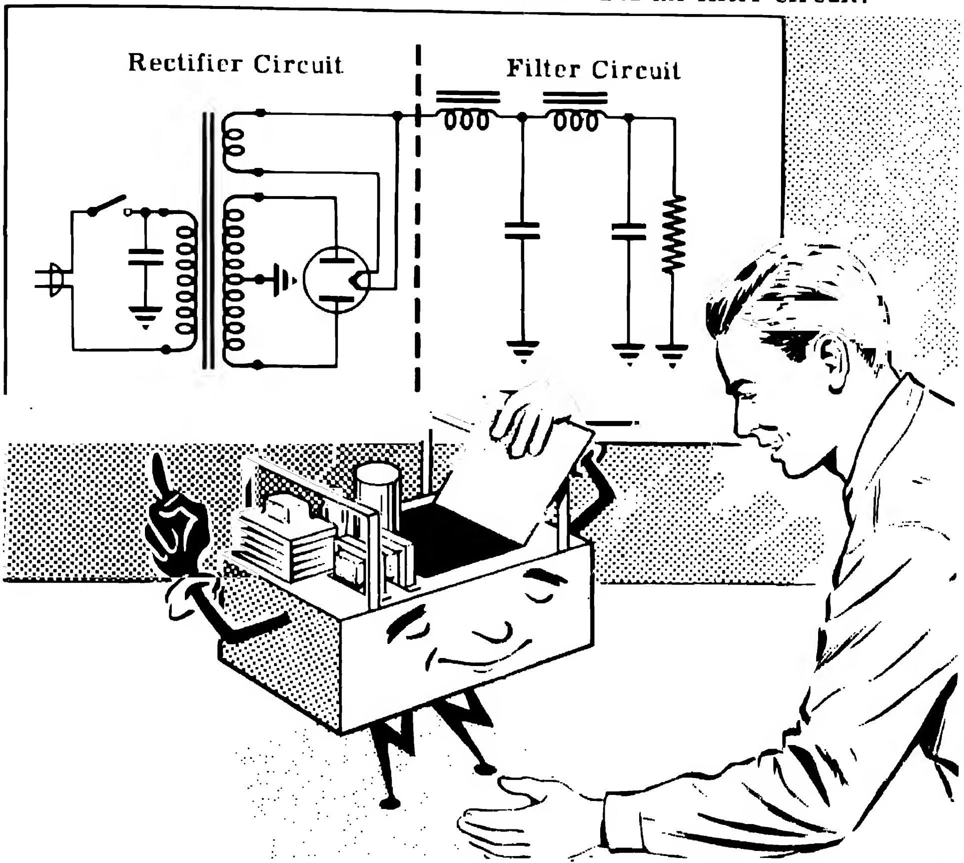
CURRENT FLOW IN THE FULL-WAVE RECTIFIER CIRCUIT - Current flows from the rectifier tube cathode to whichever plate is positive, then through one half of the secondary winding to the chassis ground. From the ground point it flows through the chassis to one end of the load resistor then through the load resistor back to the rectifier tube cathode.



FILTER CIRCUITS

What You Have to Know about Power Supplies

Learning all about the various power supplies is going to be a simple job. Why? Because you can open up any power supply and find that it contains only two major circuits—the rectifier circuit and the filter circuit.



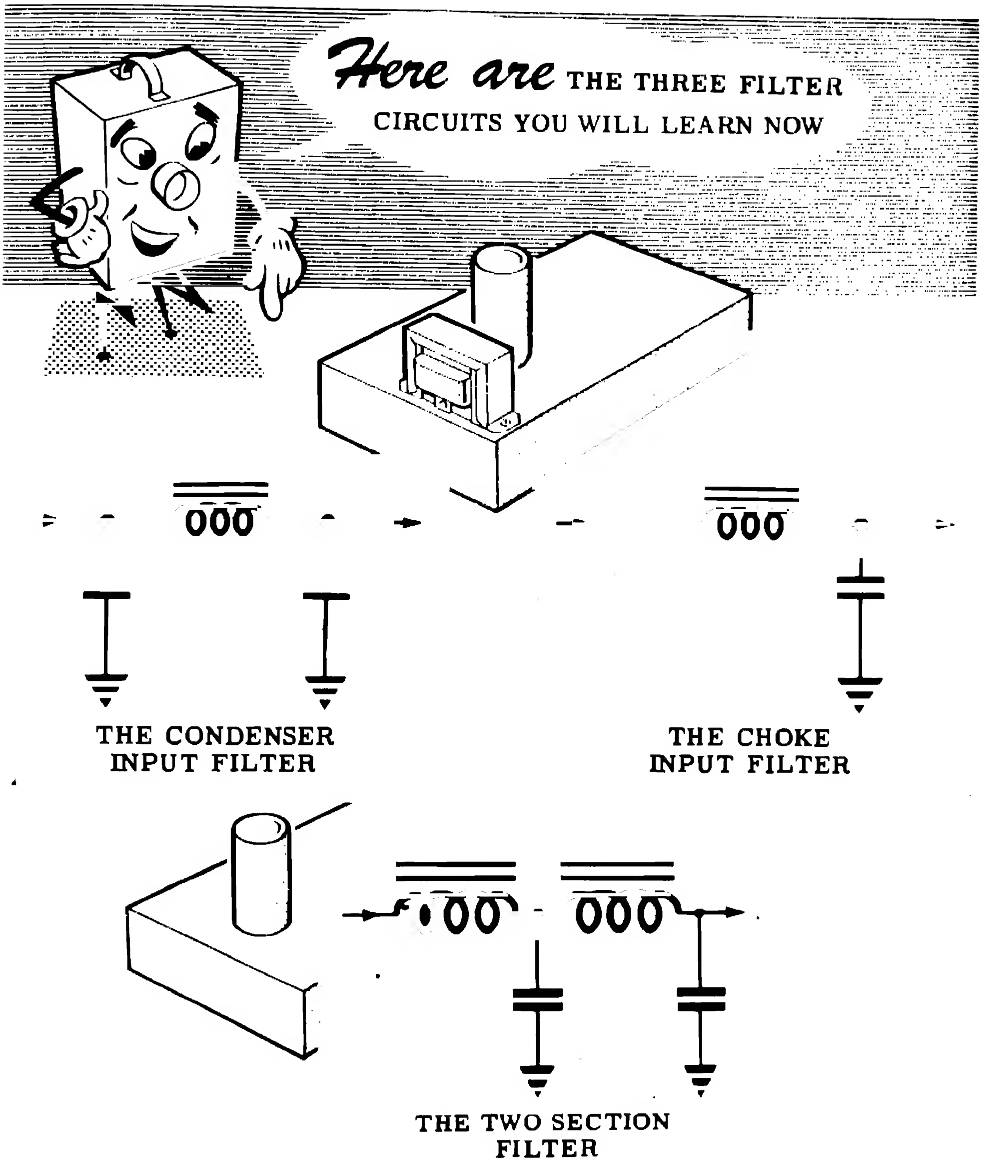
You already know that there are only two types of rectifier circuits in general use—the full-wave and the half-wave rectifiers—and they both perform the same job of changing AC into pulsating DC. There are only three types of filter circuits that are in general use. These filter circuits all have one thing in common—they remove the ripple from the pulsating DC output of the rectifier.

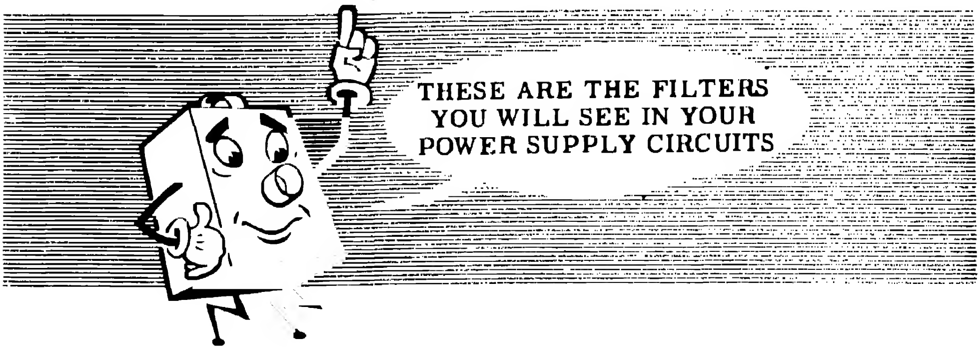
In addition, there is only one basic type of voltage regulator tube which is used with power supplies. As its name implies, this tube maintains the output voltage of a power supply at a required value in spite of line voltage fluctuations or variations of load current.

Know these power supply circuits and you know almost all you will ever have to know about power supplies. This is true because nearly every power supply that exists consists of various combinations of basic rectifier circuits, basic filter circuits, and voltage regulator tubes.

The three most common types of filter circuits used are shown on the next sheet.

Power Supply Filter Circuits





FILTER CIRCUITS

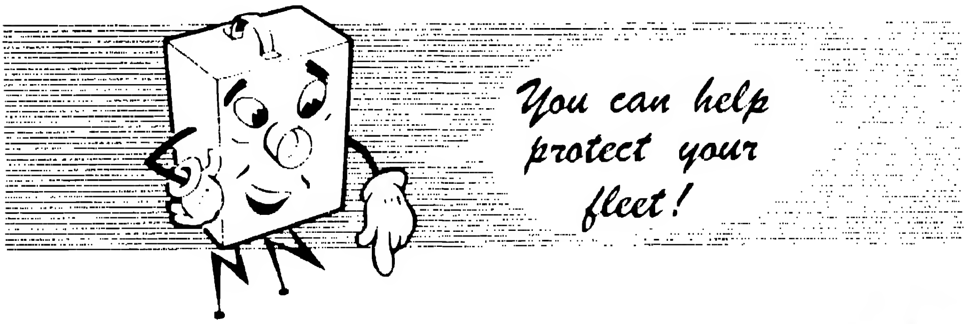
Why It Is Important to Study the Operation of the Filter

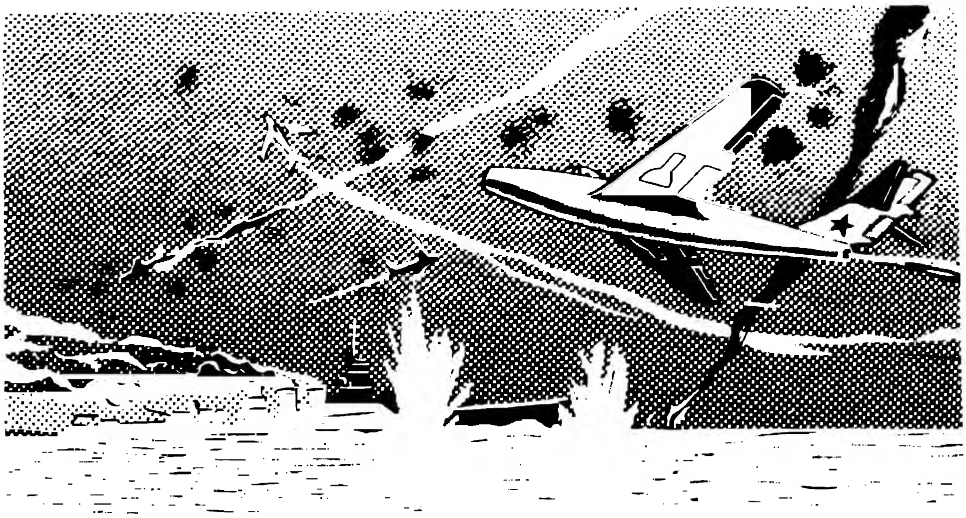
By this time you understand the important role that power supplies play in electronic equipment.

You know that, if the power supply does not work, the entire piece of equipment is a casualty You also know that it will be your job to make sure that the electronic equipment in the Fleet is in good working order at all times. This means that the numerous power supplies contained in one piece of electronic equipment must be working properly. If the filter in a power supply were to go bad, the power supply would not supply DC power; as a result, the entire equipment—whether it be a radar, a receiver or a simple vacuum tube voltmeter—would become inoperative. For example, one small filter condenser shorting out can prevent a radar system like the SG-6 (consisting of some 200 tubes) from doing its job of detecting enemy ships and airplanes.

This is why it is so important for you to study filter circuits and understand their operation. Then, when they go bad, you will be able to troubleshoot them quickly and easily.

Remember, the Navy needs good troubleshooters who can help to protect the Fleet against enemy attacks.





FILTER CIRCUITS

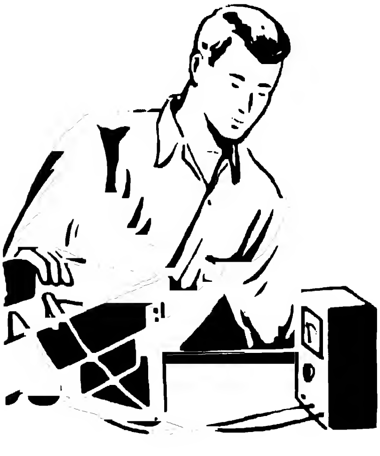
How You Will Learn About Filter Circuits

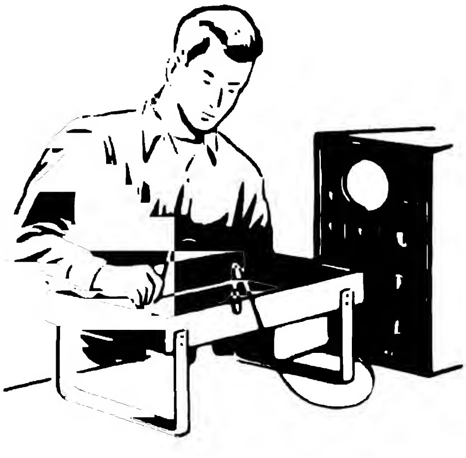
You have already been told that the purpose of a filter is to take the pulsating DC from the rectifier, smooth out its ripple and convert it to pure DC. To get a good idea of how filters work, you are going to:

1. Find out how each component in the filter circuit is effective in filtering.

2. Build the various filter circuits and observe how the filter components work together in them.

3. Compare the different filters and find out their characteristics and application.

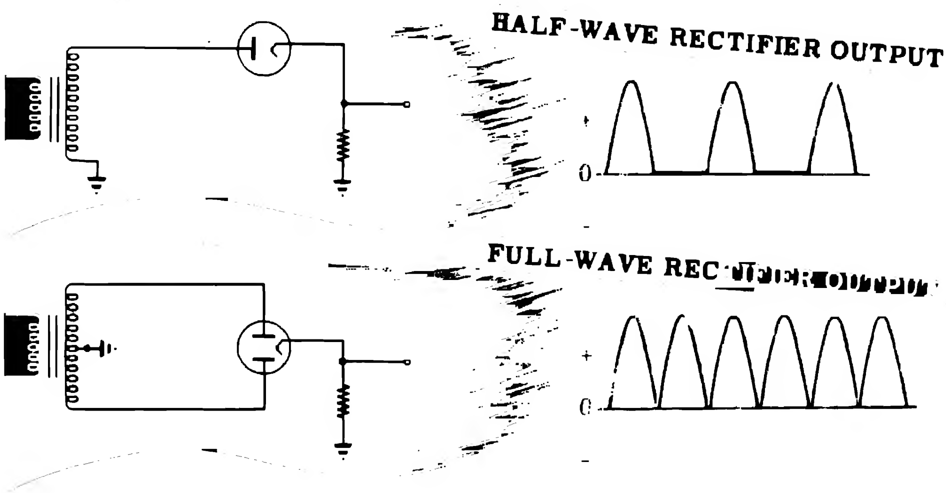




FILTER CIRCUITS

Characteristics of the Rectifier Output

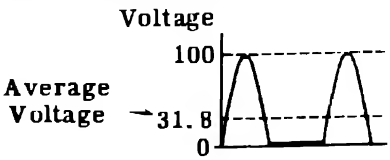
You have been told that electronic circuits in general require a source of about +350 volts DC and a source of 6.3 volts AC in order to operate. The power supply transformer supplies the 6.3 volts AC directly to the heaters of the tubes requiring it. The transformer feeds high voltage AC into the rectifier and rectifier puts out pulsating DC that looks like this:



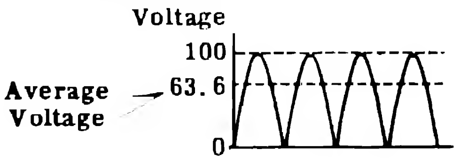
The electronic circuits which are connected to the power supply output cannot use a pulsating voltage of this sort. What these circuits require is a steady DC voltage with as little pulsation as possible. The purpose of the filter circuit is to remove the pulsations from the rectifier output and deliver a steady DC voltage.

The output of a rectifier tube consists of pulses of current which always flow in the same direction through the load resistor. The current rises from zero to a maximum and then falls to zero, repeating this cycle over and over again. At no time does the electron current through the load resistor change its direction and flow from the filament to ground. The voltage resulting from this flow of electrons through the load resistor is a voltage that rises from zero to a maximum and then falls back to zero, repeating this cycle over and over again. This voltage takes on the shape of half sine waves. In the case of a half-wave rectifier the average DC voltage is 31.8 percent of the peak value. In the case of a full-wave rectifier the average DC is 63.6 percent of the peak value.

HALF-WAVE RECTIFIER OUTPUT



FULL-WAVE RECTIFIER OUTPUT



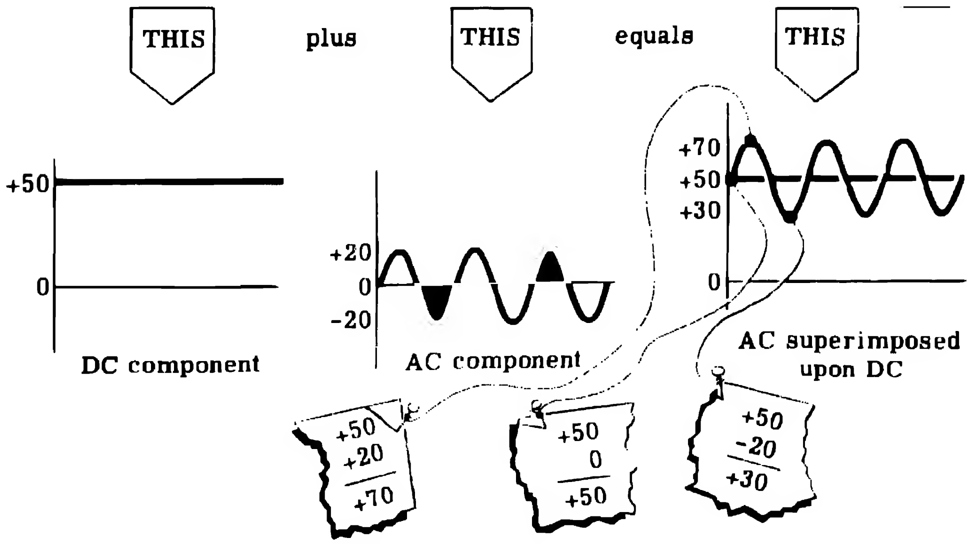
FILTER CIRCUITS

AC and DC Components

If you connect a DC voltmeter across the rectifier output you will get a reading. If you connect an AC voltmeter across the rectifier output, you will also get a reading. This AC reading is a result of the output voltage variation. Therefore, the output of the rectifier can be considered as a DC voltage with an AC voltage superimposed upon it. You can look upon the job of a filter circuit as the job of removing the AC portion (or AC component) of the rectifier output and allowing only the DC component to get to the power supply output terminals. If the filter succeeds in removing all of the AC from the rectifier output, only pure DC will be left.

You may now ask the question "How can a pulsating DC voltage have an AC component if the voltage rises from zero to a high positive value and falls back to zero, but never becomes negative?" You have always thought of an AC voltage as one which alternates above and below a zero voltage, first becoming positive, then zero and then negative. If the voltage never becomes negative, how can there be any AC in it?

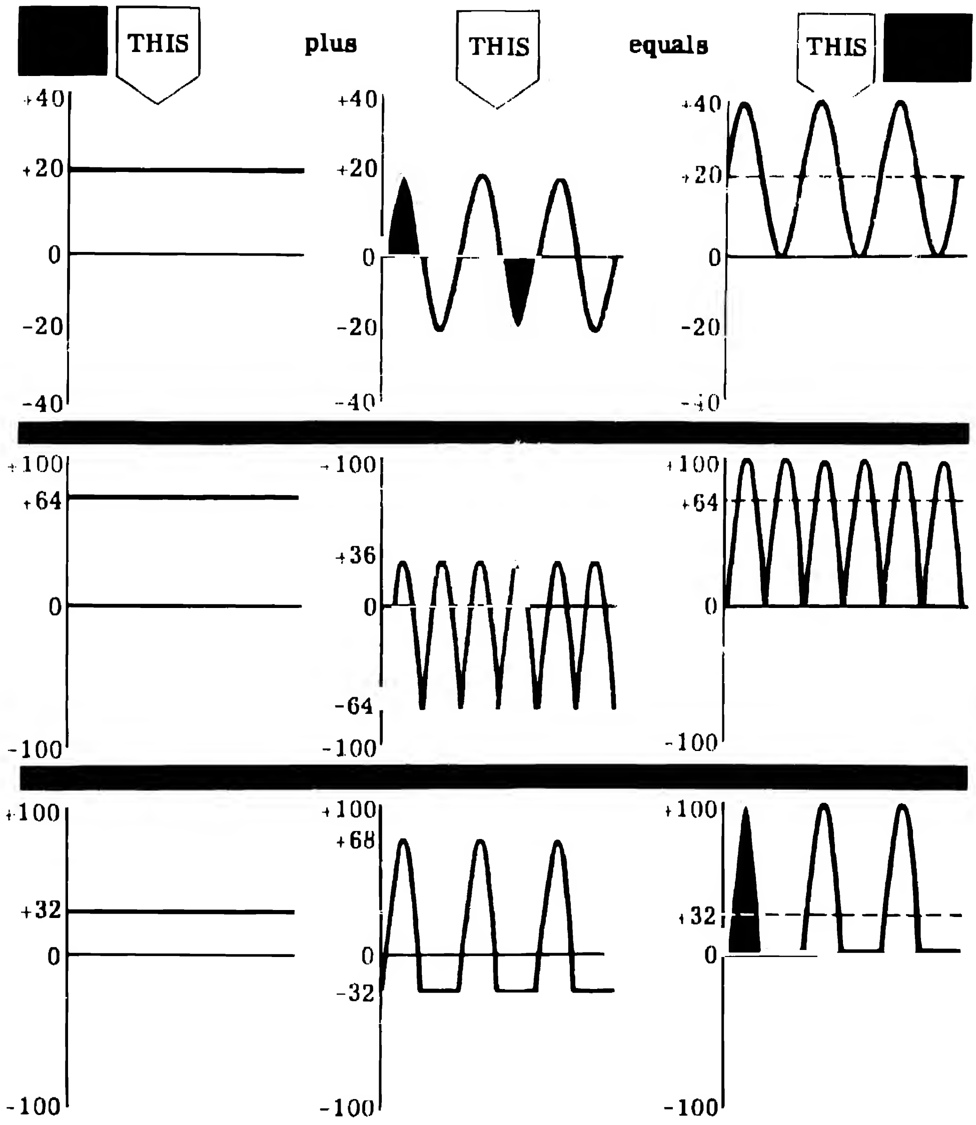
Any wave that varies in a regular manner has an AC component. Suppose you examine an example in which an AC voltage is combined with a DC voltage and the result is a voltage wave which never becomes negative. Suppose you have a voltage of +50 volts DC and you combine it with an AC voltage which varies from +20 volts through zero to -20 volts.



When the +20 volt AC peak is added to the +50 volts DC, the result is +70 volts. When the 0 volt point on the AC wave is added to the +50 volts DC, the result is +50 volts. When the -20 volts AC peak is added to the +50 volts, the result is +30 volts. The total result is a DC voltage which varies from +50 volts—up to +70 volts and down to +30 volts. The voltage of the resulting wave never becomes negative and yet it consists of an AC component and a DC component.

AC and DC Components (continued)

You have seen how a DC voltage and an AC voltage can be added together to give a voltage wave which never becomes negative. Here are a few more examples:



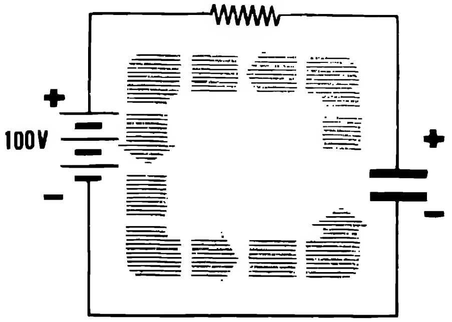
You can see that as long as a voltage varies in any regular manner, it can be broken up into a DC component and an AC component. The output of a rectifier contains both a DC component and an AC component. It is the job of the filter to remove as much of the AC voltage as is possible (and economical!) before the resulting high voltage DC is fed to the electronic circuits which require it.

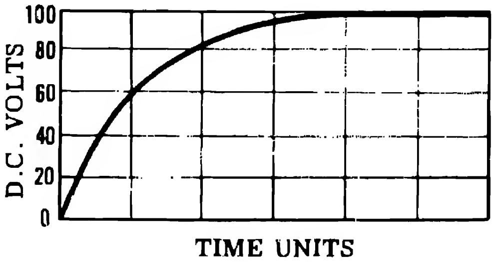
FILTER CIRCUITS

The Condenser in the Filter Circuit

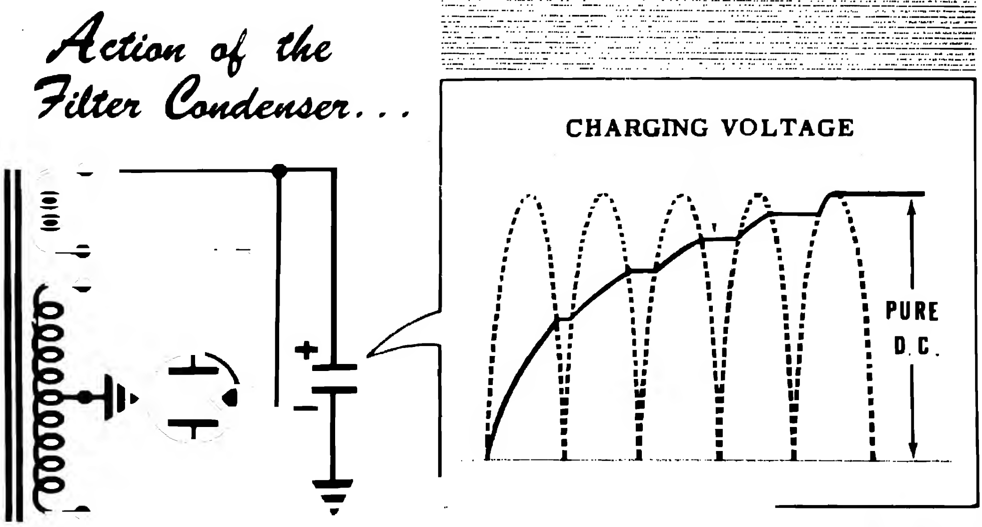
If you remove the load resistor from the output of the rectifier and replace the resistor with a large condenser, pure DC will appear across the condenser. When you find out why this takes place, you will see how this effect can be used in filter circuits.

You know that, when a condenser is placed across a battery, it charges up to the battery voltage if it is given enough time.





The same is true when a condenser is placed across the output of a rectifier. The rectifier starts charging up the condenser every time it conducts. If the condenser does not have time to charge up to the peak of the pulsating DC wave on the first half-cycle, it will do so during the next few half-cycles. After a few cycles have passed, there will be pure DC across the condenser. Because current can flow in only one direction through the rectifier, the condenser will not discharge between the peaks of the pulsating DC voltage. What has been the effect of placing the condenser across the output of the rectifier? By charging up, the condenser has filtered out the ripple in the pulsating DC, leaving pure DC.

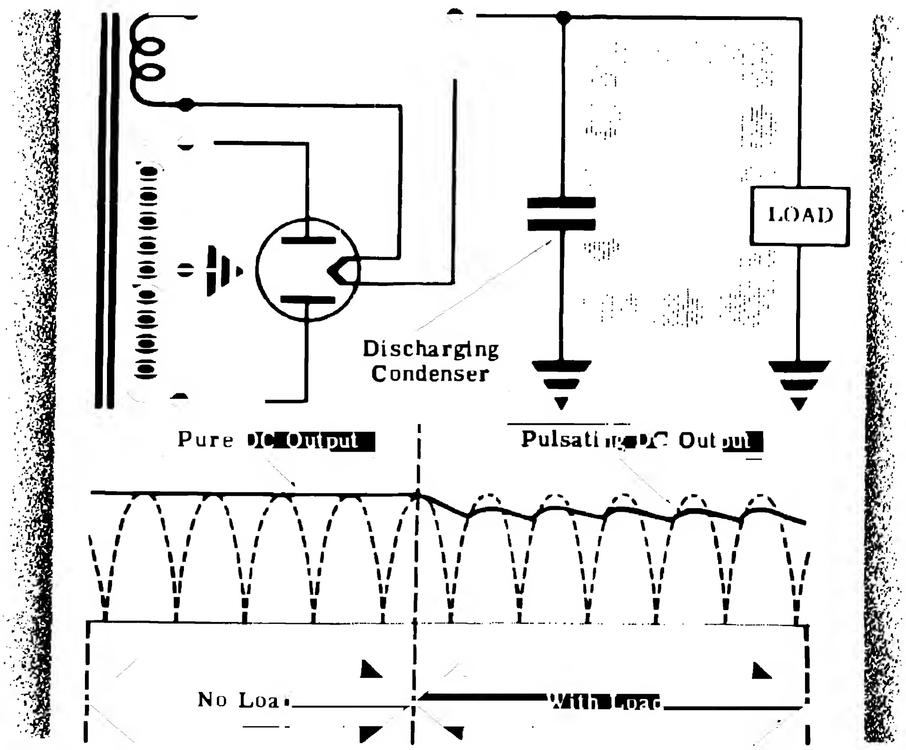


The Condenser in the Filter Circuit (continued)

If a power supply did not have to supply current to other circuits, pure DC voltage could be obtained simply by connecting a condenser from the rectifier filament to ground. However, the various electronic circuits attached to the power supply B+ voltage do draw a certain amount of current. The current drawn by these electronic circuits is called the load current, and the effect of this load current can be duplicated by connecting a load resistor across the rectifier output and ground.

You know from your study of RC circuits in Basic Electricity that when a resistor is placed across a charged condenser, the condenser will discharge through the resistor. The speed of the discharge will depend upon the size of the resistor. The lower the resistance the more current will be drawn from the condenser, and the faster will be the discharge.

As soon as the resistor is connected across the condenser of the rectifier circuit, that condenser will begin to discharge and the voltage will drop. The voltage, however, will not drop to zero because a new voltage peak appears at the rectifier filament 60 times a second for a half-wave rectifier and 120 times a second for a full-wave rectifier. This voltage peak will recharge the condenser, and then the condenser will proceed to discharge through the resistor until the next voltage peak comes along. The result will be a pulsating DC output. Notice that the pulsations are much smaller than you would get with no condenser.



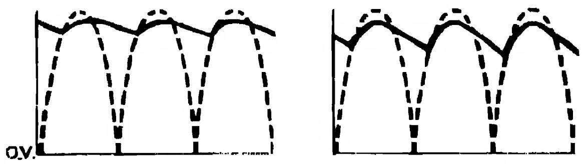
FILTER CIRCUITS

The Condenser in the Filter Circuit (continued)

The result of placing a load on the single filter condenser is that the output of the rectifier is no longer pure DC—it is DC upon which is superimposed an AC component. This AC component is called "ripple." It is because of this AC component or ripple that a condenser, by itself, does not constitute a satisfactory filter. Additional filtering components have to be added to remove the ripple and make the final B+ output as close to pure DC as is possible and economical. Just why ripple in the B+ output is so undesirable is something you will learn when you come to the study of amplifiers.

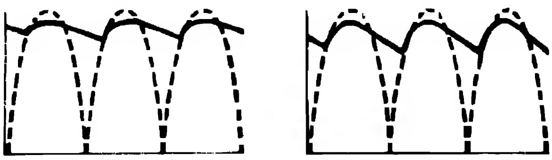
The amount of ripple resulting from a load placed across a single filter condenser depends upon the size of the load, the size of the condenser and the type of rectifier. The larger the condenser the more electrons it can accumulate on its plates, and it will discharge a smaller amount when a load is put across it. The larger the load current drawn out of the condenser the larger will be the voltage drop, and the larger will be the ripple. Since half-wave rectifiers will charge the condenser 60 times per second, there will be more time for the condenser to discharge through the load than with a full-wave rectifier which charges the condenser 120 times per second. Thus the ripple will be greater for a half-wave rectifier than for a full-wave rectifier because the voltage will drop a greater amount during pulses.

The larger the load the greater the ripple



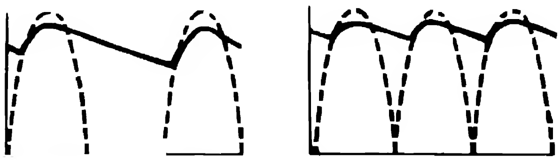
Load = 50ma. Load = 100ma.

The smaller the capacity of the condenser the greater the ripple



Large filter condenser 50 ma. load — Small filter condenser 50 ma. load

Same load, same filter condenser



Half-wave rectifier — Full-wave rectifier

FILTER CIRCUITS

Filter Condensers

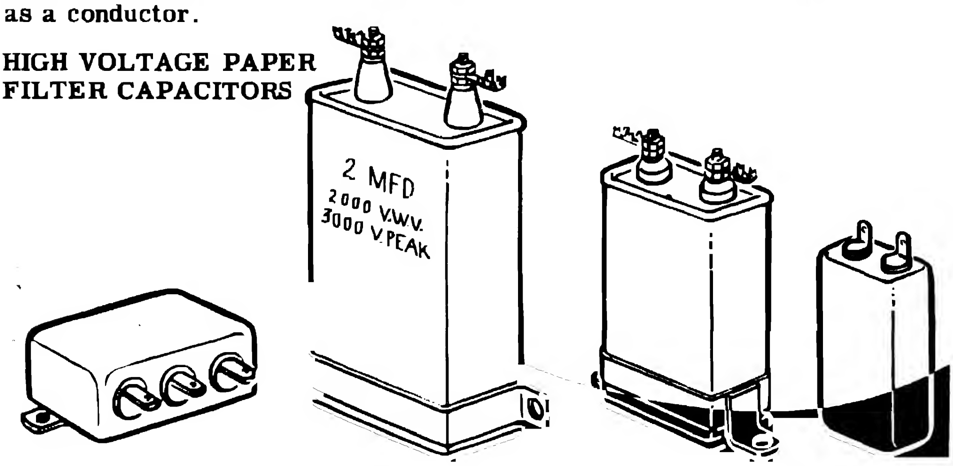
Filter condensers (capacitors) used in power supplies are of two types: (1) paper dielectric condensers and (2) electrolytic condensers.

Paper condensers are constructed of alternate layers of metal foil and waxed paper rolled together. The waxed paper is the dielectric with the metal foil being used as plates. Paper condensers smaller than 1 mfd are used throughout most electronic equipment and larger values are sometimes used as filter condensers in power supplies.

Paper condensers are not polarized and when operated within their voltage rating they last much longer than electrolytic condensers. However, large sizes of paper condensers are bulky and relatively expensive. They are normally not made larger than 16 mfd.

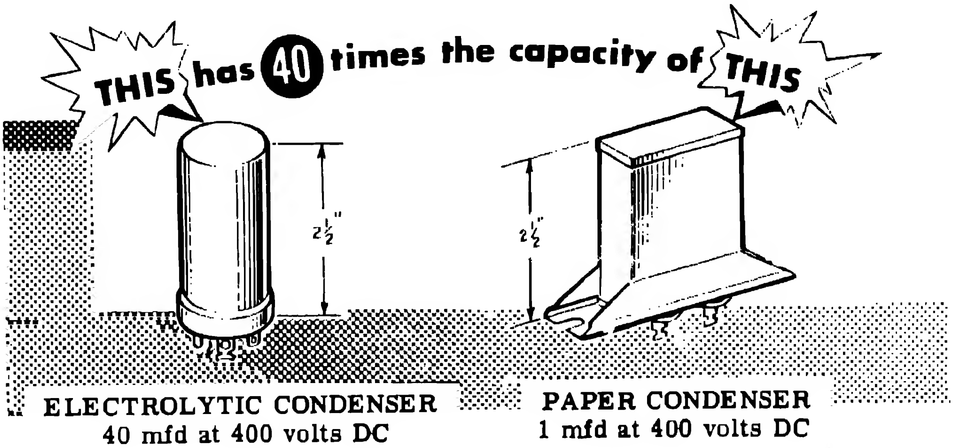
High voltage power supplies use paper filter condensers which are oil impregnated and will withstand greater peak voltages than those impregnated with wax. Condensers are rated according to direct current working voltage (DCWV) and also in peak voltage. The DCWV is the maximum voltage the condenser is designed to operate at continuously. The peak voltage is the voltage above which the condenser dielectric will break down and act as a conductor.

HIGH VOLTAGE PAPER FILTER CAPACITORS



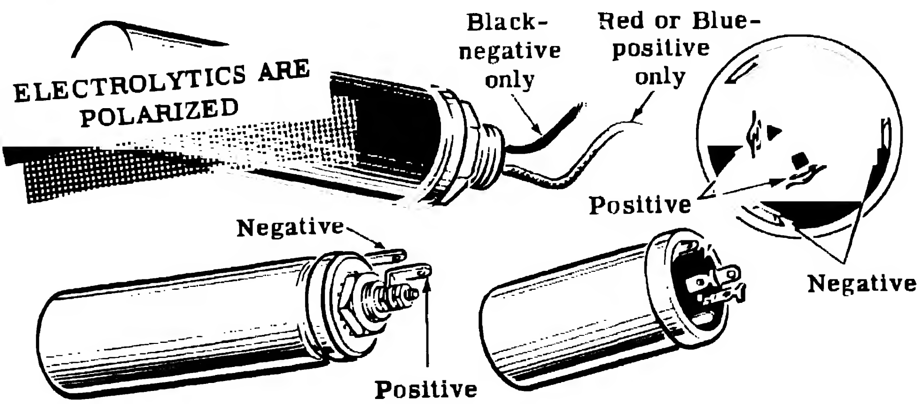
Filter Condensers (continued)

Electrolytic condensers are usually used as power supply filter condensers because they can be made in very large sizes at low cost and are much smaller physically than paper condensers of the same capacity Electrolytic condensers are made in larger sizes than paper condensers with the usual values being between 2 mfd and 1000 mfd.



Power supplies rated at 600 volts or less usually use electrolytic filter condensers but when a higher voltage rating is required paper condensers are used. Electrolytics are polarized and failure to observe the correct polarity will not only permanently damage the condenser but may also cause it to break open and damage other parts.

While paper condensers have no leakage current (flow of direct current across the condenser dielectric) electrolytic condenser dielectrics are not perfect insulators and a leakage current flows even during normal operation. The leakage current is greater in the wet electrolytic than in the dry types. If the voltage rating of an electrolytic condenser is exceeded the leakage current increases and may damage the dielectric.



Filter Condensers (continued)

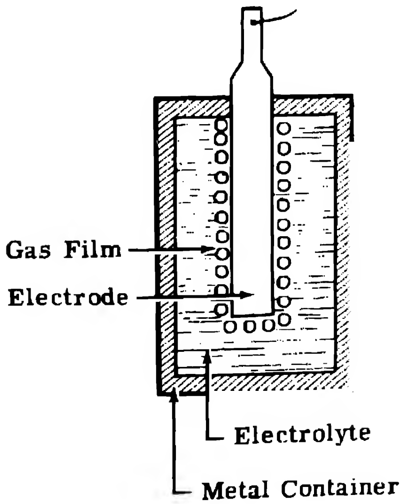
Electrolytic condensers are of two types: (1) wet and (2) dry.

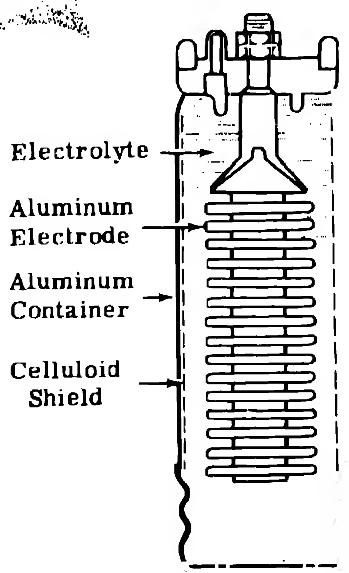
A wet electrolytic condenser consists of an aluminum electrode immersed in a solution called an electrolyte. When the electrode is connected to the positive terminal of a DC voltage source and the electrolyte container is connected to the negative terminal, current flows through the electrolyte. This current flow results in chemical action which causes a film to form on the electrode surface. This film acts as a dielectric, insulating the electrode from the electrolyte These two elements then act as plates in a condenser—the electrode becoming a + terminal, and the electrolyte a - terminal. The connection to the electrolyte is made through the container.

Reversing the polarity of the voltage applied to the condenser breaks down the dielectric completely. A momentary overload in the correct polarity punctures the dielectric but application of the rated voltage reforms the dielectric so that wet electrolytics are said to be self-healing.

The capacitance of an electrolytic condenser is greater than that of a paper condenser of equivalent physical size because the dielectric film is very thin, enabling close spacing between the condenser plates. The positive plate surface is roughened and the liquid electrolyte negative plate follows the rough surface of the positive plate resulting in greater plate area in a given space.

Wet Electrolytics... CONSTRUCTION

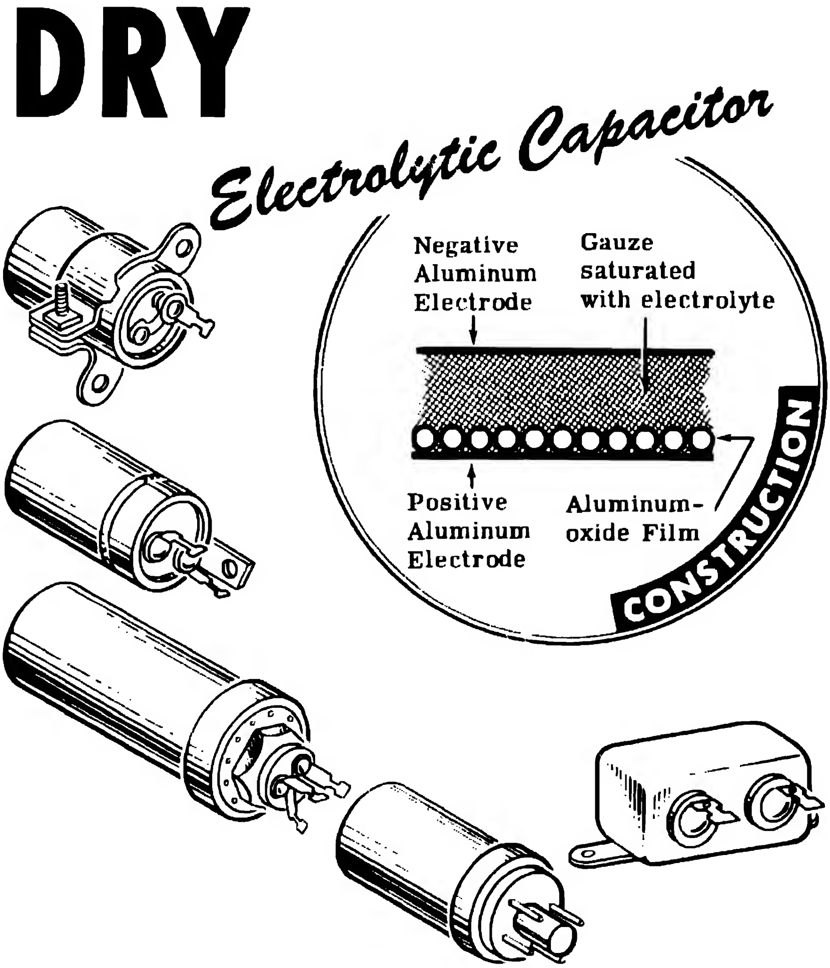




Filter Condensers (continued)

Dry electrolytic condensers use an electrolyte in the form of paste. A cloth impregnated with the electrolytic paste is rolled between alternate layers of aluminum foil in the same manner as that used to make paper condensers. One layer of metal foil is used as a positive plate of the electrolytic condenser and the other layer of metal foil is used to contact the negative plate (electrolyte) of the condenser.

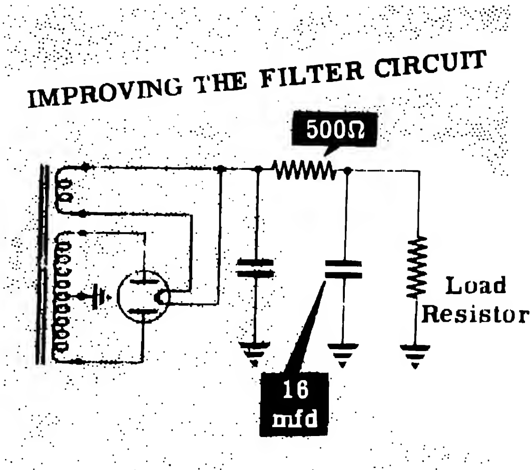
A dry electrolytic condenser operates in the same way as a wet electrolytic except that it is not self-healing when the dielectric has been punctured. Both types of electrolytic condensers have a relatively short life due to the drying up of the electrolyte. Of the two, dry electrolytics generally last longer. Wet electrolytics are not often used since they dry out rapidly and must be mounted upright to prevent leaking of the liquid electrolyte. Several types of dry electrolytic condensers are illustrated below.



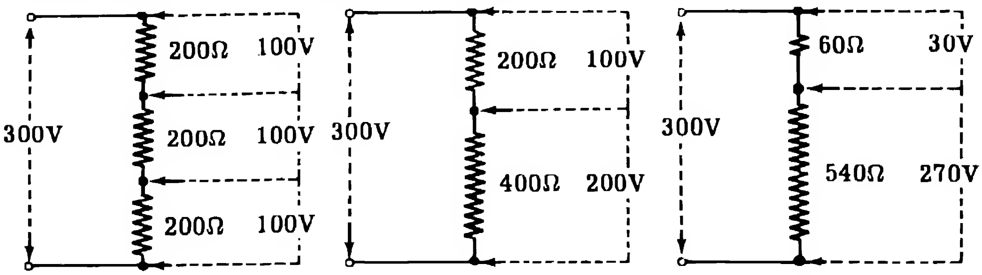
Improving the Operation of the Filter

You saw on a preceding sheet that the larger you make the filter condenser, the lower will be the AC component or ripple in the output. Filter condensers can be made very large in capacity and small in size, as you will see shortly, but there are size limitations that cannot be exceeded. A filter condenser of practical size might reduce the AC component to about 25 volts AC, but this is not good enough. Many electronic circuits require a B+ voltage that cannot have more than 3 or 4 volts of AC present in a DC output of 350 volts—the AC component must be less than 2 percent or even less than 1 percent of the total output voltage. No filter condenser of practical size can do this job alone—other filtering components must be added.

Suppose you set up a circuit consisting of a 500 ohm resistor connected in series with a 16 mfd condenser as shown in the illustration. If you connect this circuit to the rectifier and the single filter condenser previously used, you will be putting into this new filter circuit 350 volts DC upon which is superimposed about 25 volts of AC. To understand how this circuit removes the AC ripple voltage you will have to find out something about voltage dividers.



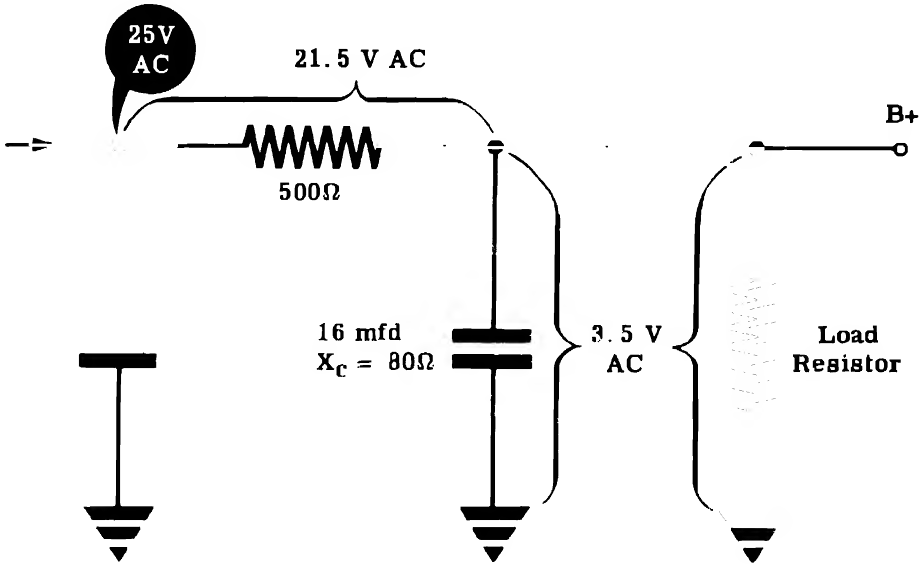
You know from your work with DC series circuits in Basic Electricity that when you place a DC voltage across three equal resistors, one third of the total voltage appears across each of the resistors. From this it can be seen that if you have two resistors and one is twice the resistance of the other, 1/3 of the voltage will appear across the small resistor, and 2/3 of the voltage will appear across the larger resistor. Similarly if one resistor contains 1/10 of the total resistance and the other resistor contains 9/10 of the total resistance; 1/10 of the total voltage appears across the small resistor and 9/10 of the total voltage appears across the large resistor. From this you can see that a DC voltage divides itself across two resistors in direct proportion to the size of the resistors.



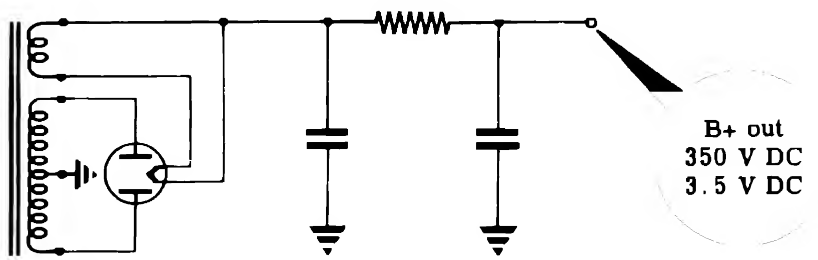
FILTER CIRCUITS

Improving the Operation of the Filter (continued)

When the 25 volts ripple from the input filter condenser appears across the resistor and output capacitor, as shown below, the resistor presents 500 ohms resistance and the condenser presents only 80 ohms reactance to 120 cycle AC ripple. This means that the AC ripple voltage is divided across a total of 580 ohms. About 1/7 of the AC voltage will appear across the condenser and 6/7 of the AC voltage will appear across the resistor. The AC voltage across the condenser and therefore between B+ and ground will be 1/7 of 25 volts, or about 3.5 volts AC.



You see that the simple addition of a 500 ohm resistor and another filter condenser has succeeded in reducing the ripple voltage down to 3.5 volts which is about 1 percent of the total DC output. This amount of filtering is satisfactory for most applications in electronics.



The Faults of RC Filters

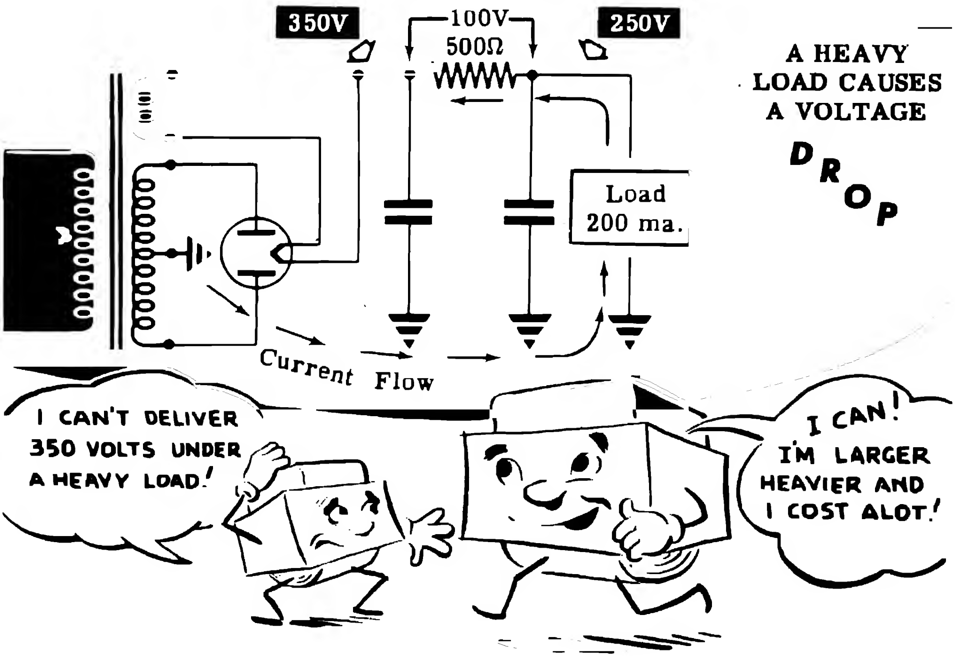
The filter circuit you now have consists of two condensers and one resistor making up an RC filter network. This filter is compact in size, low in cost and is used in many small commercial radios and in some Navy equipment.

There are two reasons why this RC filter cannot be used in most Navy power supplies—it is difficult to get a high B+ voltage when a large load current is required; and there is a large change in B+ voltage whenever the load current changes.

Suppose you consider the first fault—the difficulty of getting a high B+ voltage when a large load current is required. Many electronic equipments require that the power supply deliver 100 to 200 milliamps of current at a B+ voltage of 350 volts. All of this current must flow through the 500 ohm filter resistor and will, according to Ohm's law, cause a drop in voltage across that resistor. This means that if 200 milliamps flow through 500 ohms, the voltage drop across the resistor will be—

$$E = IR = 0.200 \text{ amp} \times 500 \text{ ohms} = 100 \text{ volts}$$

Instead of getting 350 volts out of the filter, you will get only 250 volts (350 - 100 = 250V). In order to get 350 volts out of the filter, the transformer will have to be made so that it will feed a much higher voltage into the rectifier to make up for the loss of voltage across the resistor. Increasing the voltage output of the transformer makes it larger, heavier and more expensive—three very undesirable qualities.



FILTER CIRCUITS

The Faults of RC Filters (continued)

You have seen that one fault of the RC filter is that it causes a large voltage drop across the filter resistor which means that the transformer must put out a higher AC voltage in order to compensate for this loss. The second fault of RC filters is even more seious—a small change in the load current causes the B+ output to vary by many volts.

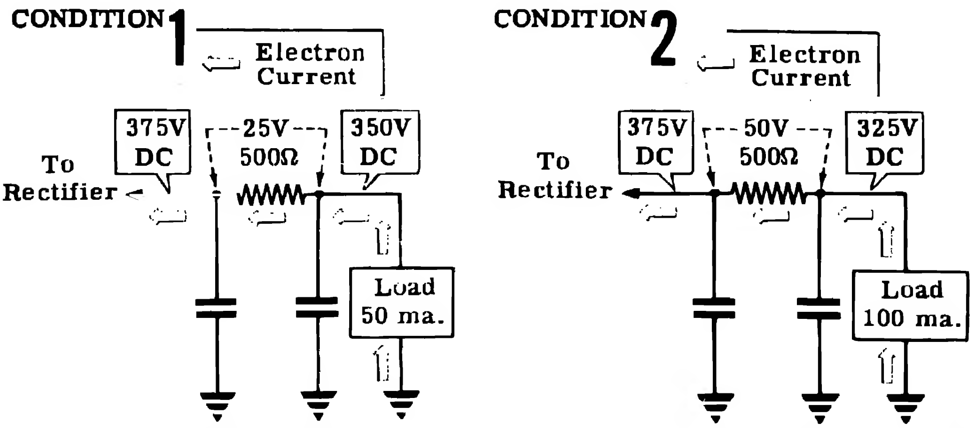
You have read in the introduction to this section that it is important for the B+ voltage output to remain fairly stable in spite of changes in load current. Many types of electronic equipment draw varying amounts of load current from the B+ voltage supply, but the voltage change must remain small in spite of this.

As an example, suppose that you have a unit of electronic equipment that draws 50 ma. from the B+ supply under one set of conditions, and then the conditions change so that 100 ma. are drawn from the B+ supply. First you have 50 ma. flowing through the 500 ohm filter resistor and then you have 100 ma. flowing through that same resistor. Suppose that the voltage coming out of the filter is 350 volts and 50 ma. are being drawn by the load. The voltage drop across the 500 ohms resistor will be $E = IR = .050 \times 500 = 25V$. Suddenly an additional 50 ma. are drawn through the 500 ohm load resistor (making a total of 100 ma.). The result is an increased voltage drop across the 500 ohm resistor.

$$E = IR = 0.100 \times 500 = 50V$$

Since the voltage drop has increased 25V, the output voltage must decrease by the same amount.

The output voltage will decrease from 350V to 325V when the load current increases from 50 to 100 ma.

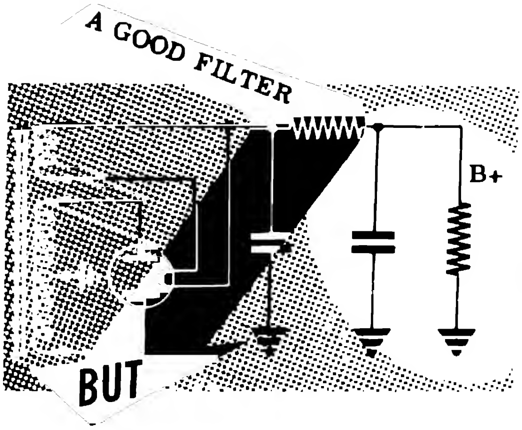


Similarly a change of 100 ma. in the load current will cause the B+ voltage to drop 50 volts. Such a rise and fall in output voltage is very undesirable in electronic equipment. Voltage regulator circuits might be added to compensate for this voltage change due to the filter resistor, but it would require a large and expensive circuit to compensate for changes such as are indicated here.

FILTER CIRCUITS

Using a Choke Instead of a Resistor

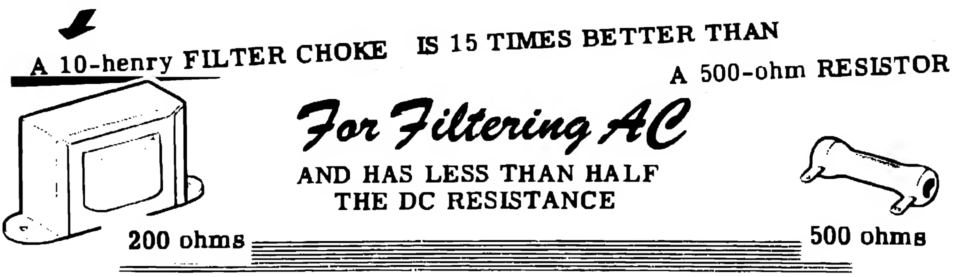
A resistor can do a fairly good job of filtering because its resistance to AC is higher than the reactance of a filter condenser to AC. When the ripple voltage is placed across this circuit, the AC voltage divides so that only a small part of this ripple voltage appears across the filter condenser and at B+. The DC voltage divides across this circuit so that most of the DC voltage appears across the filter condenser and at B+.



What the filter circuit requires is that the resistor have a high resistance for AC and a low resistance to DC. A resistor presents exactly the same resistance to both AC and DC and cannot meet this requirement. When a filter resistor is used, its size must be a compromise between these two opposing requirements.

There is, however, a certain type of component that will meet this requirement—the filter choke. From your study of AC circuits in Basic Electricity you know that a choke opposes any change of current flowing through it. In other words the inductance of a choke presents a high reactance to AC. Because a choke is made up of many turns of copper wire wound around a core, it also presents a low resistance to DC. A choke has the very qualities that are required to replace the resistor in a filter circuit.

Inductors or chokes, as used in electronic power supplies, are called "filter chokes" because they are used to "choke" out the AC. A 10-henry choke is fairly small in size and will present a reactance of about 7500 ohms to 120 cycle ripple and will have a DC resistance of about 200 ohms. Such a choke has 15 times more reactance to AC than a 500 ohm resistor, and also has less than half its DC resistance. Because of these excellent qualities you will find that chokes are used in the filter circuits of most electronic power supplies. Before you learn about the various combinations of chokes and condensers that are used in filter circuits, suppose you find out about the construction of these components.



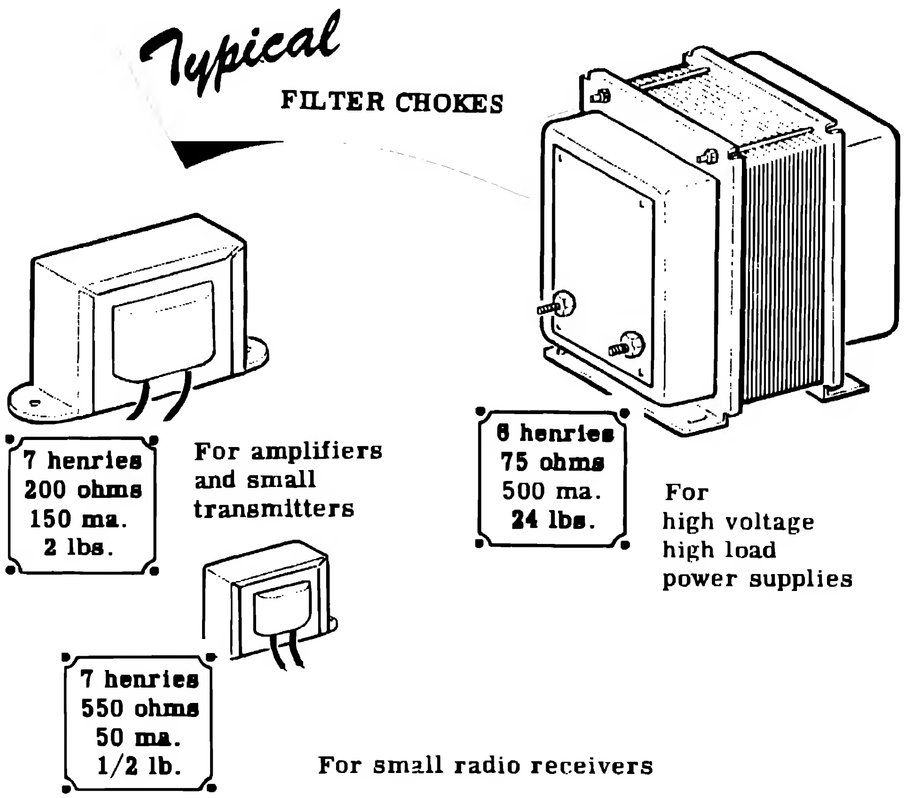
FILTER CIRCUITS

Filter Chokes

The purpose of a filter choke is to furnish a high impedance to AC ripple voltage and a low resistance to DC current. A choke consists of many turns of copper wire wound around a laminated iron core. The total impedance of the choke depends upon the number of turns of wire and the size, shape and material of the core. The DC resistance of the choke depends upon the total length of wire used and the diameter of the wire.

By increasing the number of turns of wire and by increasing the size of the core, you can raise the impedance; but this also increases the size and the weight of the choke. In addition, the increased length of wire through which the current must flow causes the DC resistance to increase. The only way to decrease DC resistance is either to decrease the number of turns (which lowers the impedance) or to increase the diameter of the wire (which increases the weight).

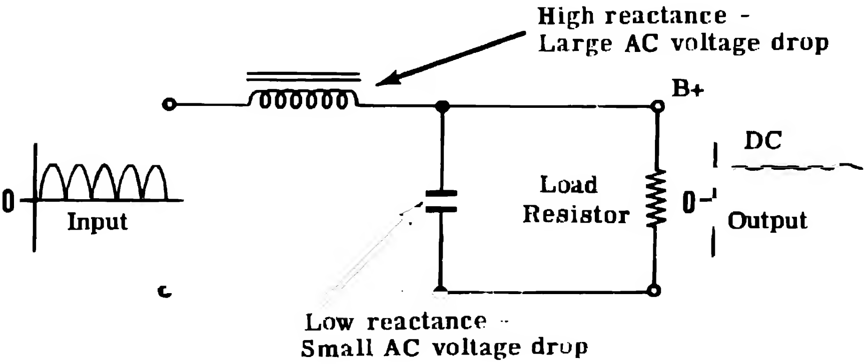
Every type of choke manufactured is a compromise of size, weight, AC impedance and DC resistance requirements. Because requirements differ according to the equipment, many different sizes of chokes are made. Chokes are rated by the amount of inductance, the DC resistance and the maximum amount of current flow.



FILTER CIRCUITS

The Single-Section Choke and Condenser Input Filters

The single-section choke input filter consists of a filter choke in series with the power supply load and a filter condenser across the load. The DC component of the rectifier output appears across the load. Most of the AC component appears across the high inductive reactance of the choke. Only a small amount of AC appears across the output filter condenser because of its low reactance. Since the load is in parallel with the output filter condenser, very little ripple appears across the load.



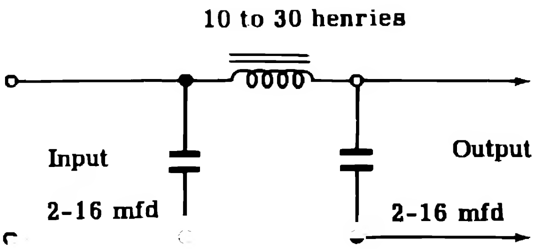
SINGLE SECTION CHOKE INPUT
FILTER CIRCUITS

A single-section condenser input filter consists of a filter condenser connected across the input terminals of a single-section choke input filter. Because of the shape of the circuit diagram, filter circuits of this type are sometimes called π type filters.

Large values of inductance and capacitance are used in condenser input filters so that they are often called "brute-force" filters. Inductance values of from 10 to 30 henries and capacitance values of from 2 to 16 microfarads are commonly used.

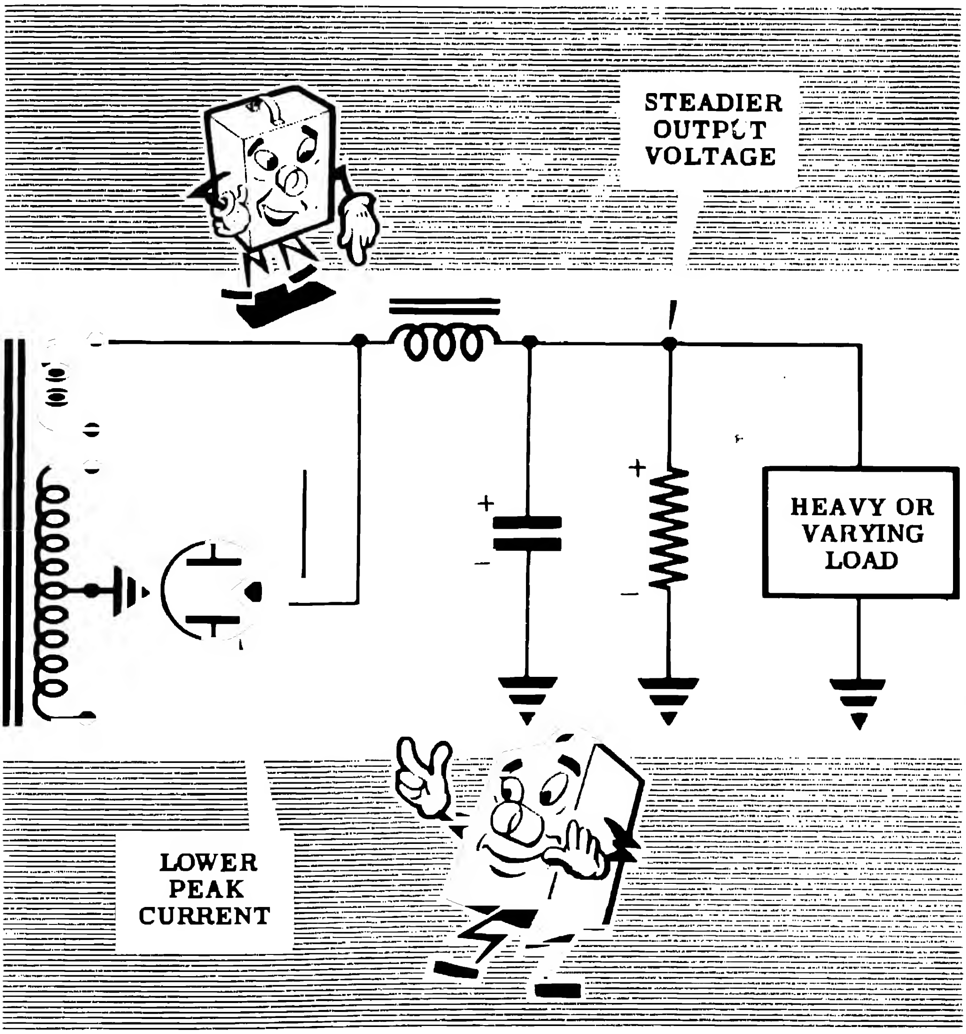
SINGLE-SECTION
CONDENSER
INPUT

Filter..... Circuit



The Single-Section Choke Input Filter

You will see that the single-section choke input filter does just a little better job of filtering than the condenser alone. The voltage output of the choke input filter is lower than the voltage output of the condenser alone. This is because the choke builds up a back emf which cancels a part of the voltage coming out of the rectifier. An important feature of the choke input filter is that it limits the peak current flowing through the rectifier tube and, as a result, there is less strain on the tube. The choke input filter also has the characteristic of holding the output voltage quite constant despite load variations. Because of these last two characteristics, choke input filters are used most commonly in power supplies which are subjected to heavy or varying loads. The results of using this type of filter for such loads are a more stable output voltage from the power supply and longer life of the rectifier tube.

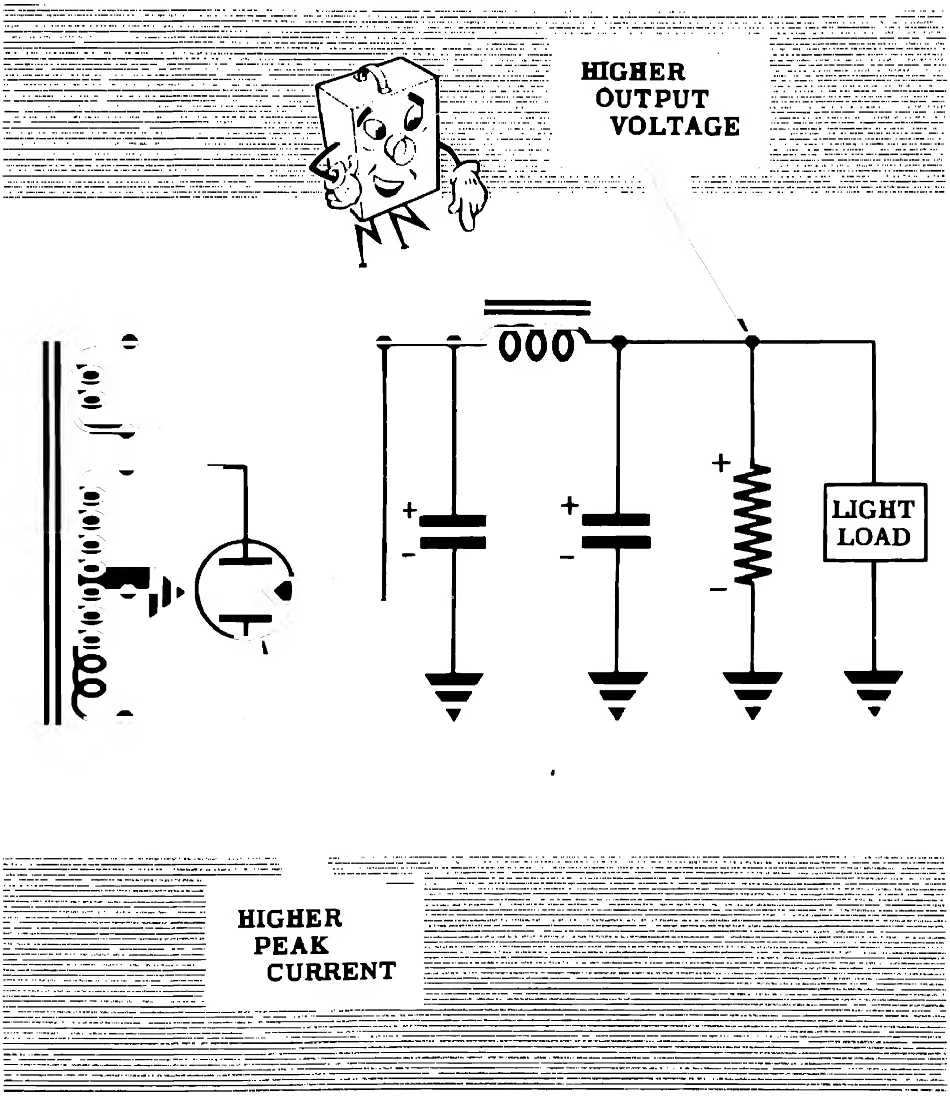


FILTER CIRCUITS

The Condenser Input Filter

By comparing these wave forms and voltages with those of the preceding filter circuits, you can see that the condenser input filter does a better job of filtering than any of the others. The voltage output of this filter is larger than it was for the choke input filter because of the charging and discharging action of the input condenser.

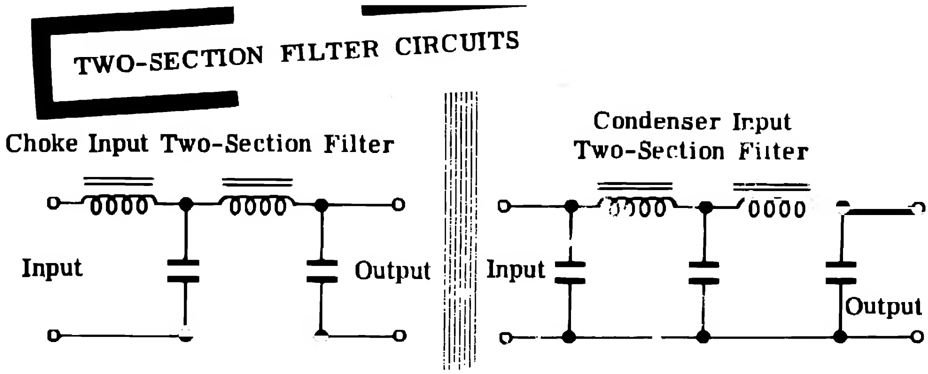
However, unlike the choke input filter, this circuit draws large peaks of current from the rectifier tube. The voltage regulation is not as good as it is for a choke input filter. The condenser input filter, very often called a "brute-force" filter, is the most widely used filter circuit for applications where the required amount of DC power is small.



FILTER CIRCUITS

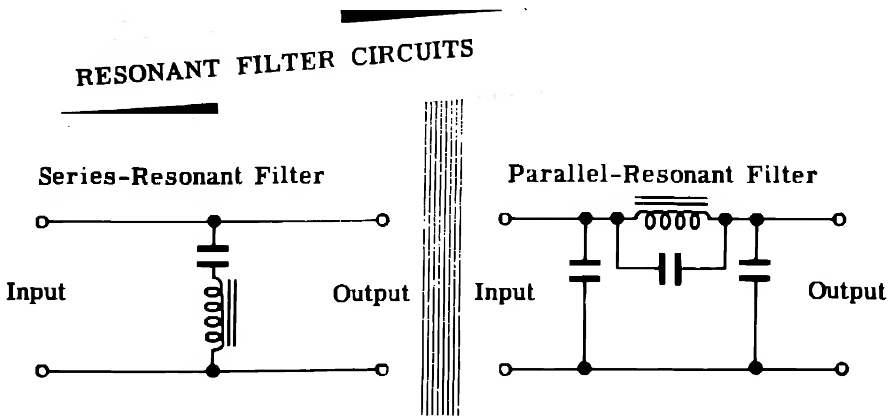
The Two-Section Filter

A two-section choke input filter circuit consists of two single-section choke input filters connected in series. Adding another condenser across the filter input terminals changes the choke input circuit into a two-section condenser input filter. Both types of two-section filters reduce the output voltage ripple to a negligible value.



Resonant filter circuits may be used in power supplies although they are usually used in other types of electronic circuits. A series-resonant filter consists of a choke and condenser connected in series across the output terminals of the rectifier circuit. You learned in Basic Electricity (series-resonant circuits) that when a choke and condenser in series are resonant, their inductive and capacitive reactance cancel each other and their total impedance is zero. Therefore, if the components used are resonant at the ripple frequency of the power supply, they will act as a short circuit across the load for that particular frequency.

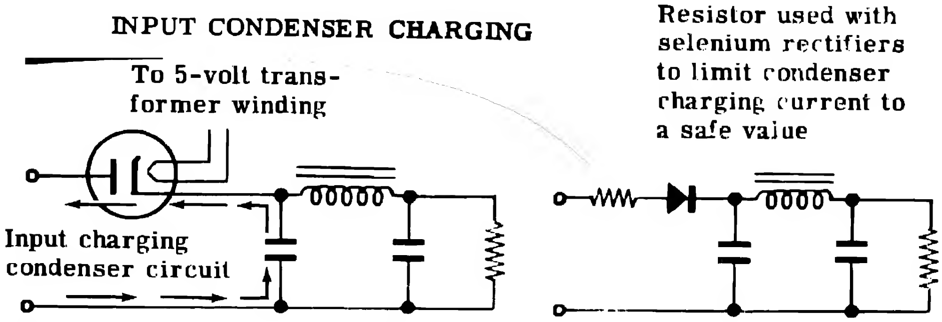
A parallel-resonant combination of L and C can be used in series with one output terminal of the power supply to provide additional filtering at the ripple frequency. The parallel-resonant circuit offers high impedance to the ripple frequency.



Filter Condenser Considerations

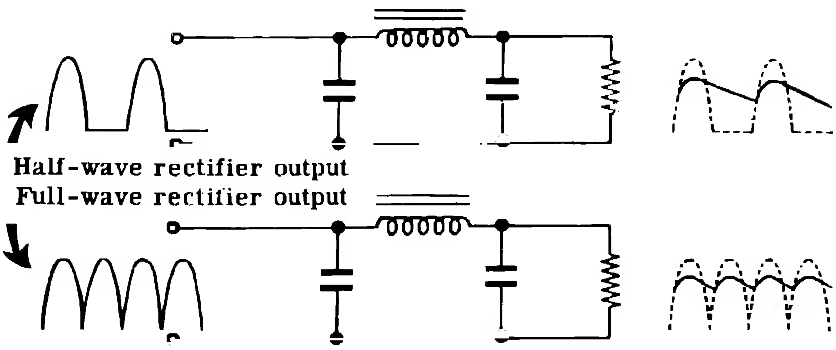
When a condenser input filter is used the instantaneous peak current of the rectifier may be much higher than the maximum current delivered to the load. The input condenser across the load circuit acts like a short circuit when a voltage is first applied to it. The initial charging current may exceed the rectifier rating. Series resistors are sometimes used with selenium rectifiers in order to limit the initial charging current of the input filter condenser.

INPUT CONDENSER CHARGING



Because of the time lapse between pulses of direct current, the output of a half-wave rectifier requires more filtering than that of a full-wave rectifier and the filtered output voltage will be lower. Filter condensers used in half-wave power supplies are usually from 2 to 4 times as large as those used in full-wave power supplies. Increasing the size of the filter condensers provides additional filtering.

Filtering HALF- AND FULL-WAVE RECTIFIER OUTPUT



The higher the frequency of the AC input voltage to a power supply the lower the value of the filter condensers required. The time between pulses is shorter at higher frequencies and the inductive action of the choke is greater at higher frequencies.

FILTER CIRCUITS

Bleeder Resistors

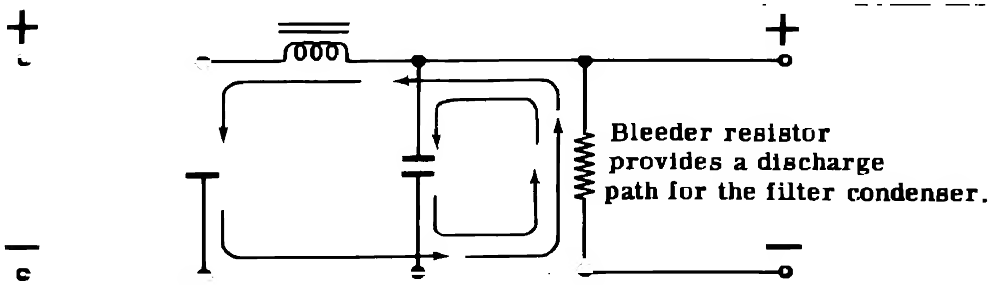
If the load is entirely removed from a power supply the voltage rises to a value much higher than normal. With no load current there is no DC voltage drop in the circuit and no discharge path for the filter condensers, resulting in a build-up in voltage across the filter condensers to a value approximately equal to the peak AC voltage applied to the rectifier tube.

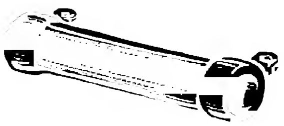
To prevent soaring of the voltage at no load, resistors are often connected across the output terminals of power supplies. These resistors called "bleeder resistors" provide a discharge path for the filter condensers and also serve as a fixed load to bleed off a constant value of current. The bleeder resistor usually draws about 10 percent of the total rated current output of the power supply.

Since a bleeder resistor prevents sharp increases in voltage output under light or no load conditions it improves the power supply voltage regulation and tends to maintain the output voltage at a constant value regardless of load. This method of voltage regulation is sufficient for most power supply applications but in many cases better voltage regulation is required.

Bleeder resistors dissipate a relatively large amount of power as heat and should be mounted in a well-ventilated position. The resistance value and power rating of the bleeder resistor depend on the maximum voltage and current ratings of the power supply. For example, if a power supply is rated at 300 volts and can supply 100 milliamperes the bleeder current should be about 10 milliamperes and the voltage across the bleeder 300 volts. The bleeder resistance (30,000 ohms) is found by dividing the voltage (300 volts) by the bleeder current (.010 ampere). The power dissipated is equal to the voltage multiplied by the bleeder current. (300 x .01 = 3 watts). The wattage rating of a resistor should be higher than the power dissipated so that a 30K, 10-watt resistor is used as a bleeder.

BLEEDER RESISTORS Improve Voltage Regulation





Bleeder resistors provide a continous load for the power supply.

FILTER CIRCUITS

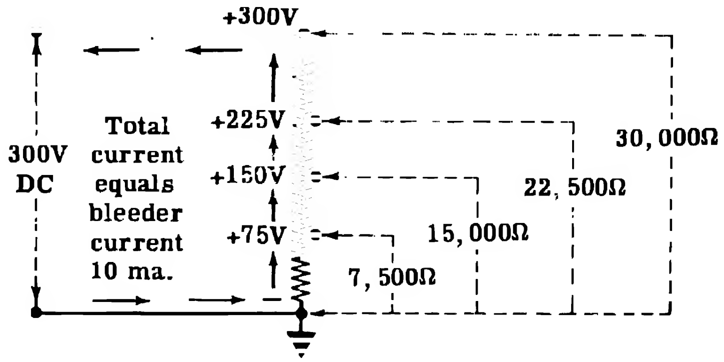
Bleeder Resistors (continued)

Bleeder resistors are sometimes tapped to provide one or more voltages lower than the maximum voltage of the power supply. The bleeder may consist of several resistors connected in series across a source of voltage with various voltages available at the resistor junctions.

When a bleeder is connected directly across the power supply output, the voltage at various points along the bleeder is exactly proportional to the resistance at that point, provided no current is drawn from any of the taps. For example, if a 30,000-ohm resistor tapped at 7,500-ohms, 15,000 ohms and 22,500 ohms is connected across the output of a 300 volt power supply the voltage divides proportionately. At the 15,000-ohm tap the voltage is one half of the total or 150 volts, at the 7,500-ohm tap it is one fourth of the total or 75 volts and at the 22,500-ohm tap it is three fourths of the total or 225 volts. The bleeder current through the resistor is 10 milliamperes.

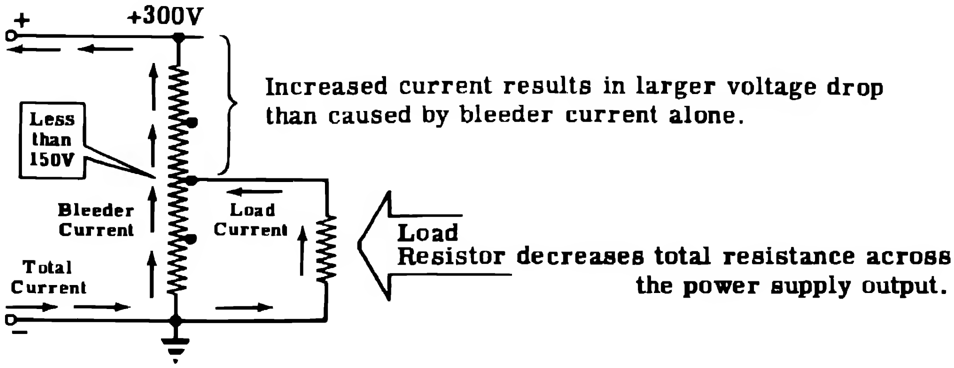
VOLTAGE DROPS

ACROSS
A TAPPED
BLEEDER
RESISTOR



The voltages available at the voltage divider taps depend on the current drawn from each tap and are affected by changes in current supplied by any of the voltage taps. When a load is connected to any of the taps its resistance is in parallel with a portion of the voltage divider. This forms a series-parallel circuit and reduces the total resistance across the circuit resulting in an increase in current drawn from the power supply. The voltage drop in the series part of the voltage divider circuit increases due to the increased current, and the voltage drop and bleeder current for the parallel part of the voltage divider are decreased.

TAPPED BLEEDER RESISTOR WITH A LOAD CONNECTED



Bleeder Resistors (continued)

A typical voltage divider for a 300 volt, 100 milliampere power supply might provide for a bleeder current of 10 milliamperes, a tap at 200 volts to supply 40 milliamperes and a tap at 150 volts to supply 50 milliamperes. To find the resistance values for each part of such a voltage divider circuit the voltage drop and current through each resistor must be found. In the illustration, points A, B, C and D provide the desired voltage taps and the resistance values of R_1, R_2, and R_3 are found as follows:

R_1 The voltage drop across R_1 (between points C and D) is 150 volts. The current flow through R_1 is only the bleeder current or 10 ma. then

$R_1 = \frac{150}{.01} = \underline{15,000 \text{ ohms}}.$

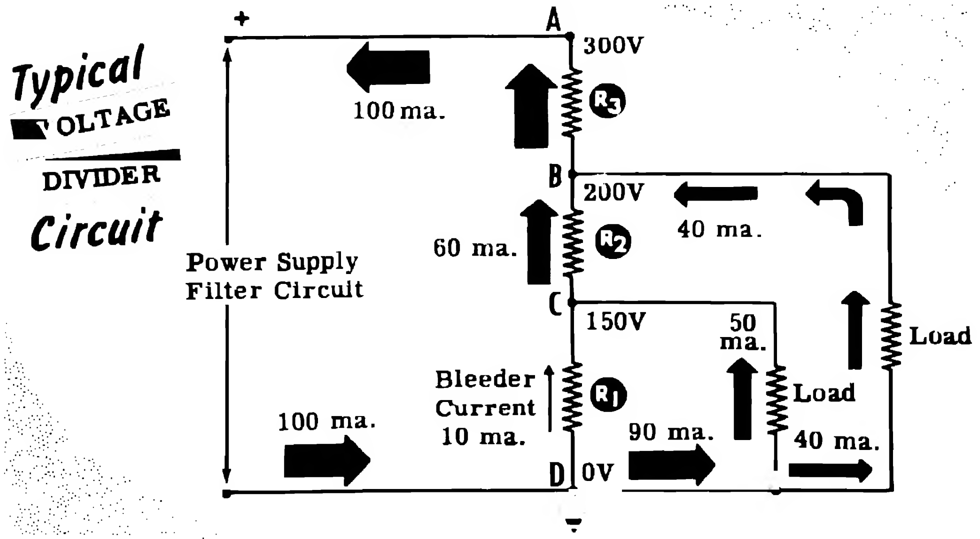
R_2 The voltage drop across R_2 (between points B and C) is 50 volts (150V to 200V). The current flow through R_2 is bleeder current, 10 ma., plus the load current, 50 ma., or 60 ma then $R_2 = \frac{50}{.06} = \underline{833 \text{ ohms}}.$

R_3 The voltage drop across R_3 (between points A and B) is 100 volts (200V to 300V). The current flow through R_3 is the sum of the bleeder current and the current through each load—10 + 50 + 40 = 100 ma. then

$R_3 = \frac{100}{.1} = \underline{1000 \text{ ohms}}.$

The wattage dissipation of each resistor is found by multiplying the current through the resistor by the voltage drop across it:

150 x .01 = 1.5 watts for R_1
50 x .06 = 3 watts for R_2
100 x .1 = 10 watts for R_3



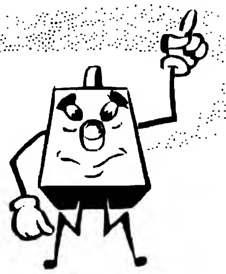
FILTER CIRCUITS

Experiment on Filter Circuits

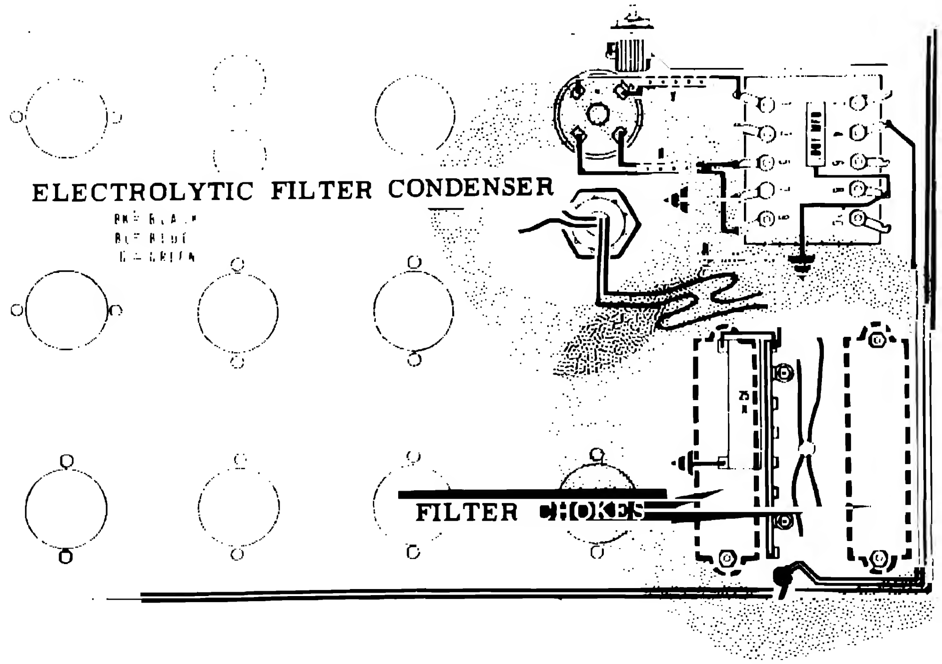
Now you are going to mount the parts required for the filter circuit in the power supply.

THIS IS WHAT YOU WILL NEED

1. **The chassis which now contains a full-wave rectifier circuit**
2. **Two filter chokes**
3. **Dual section electrolytic filter condenser**
4. **Five octal (eight prong) sockets.**

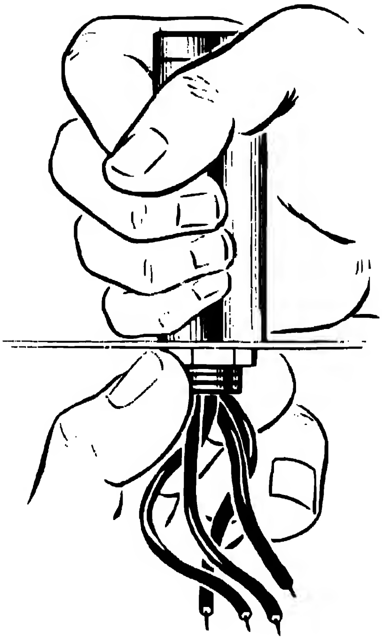


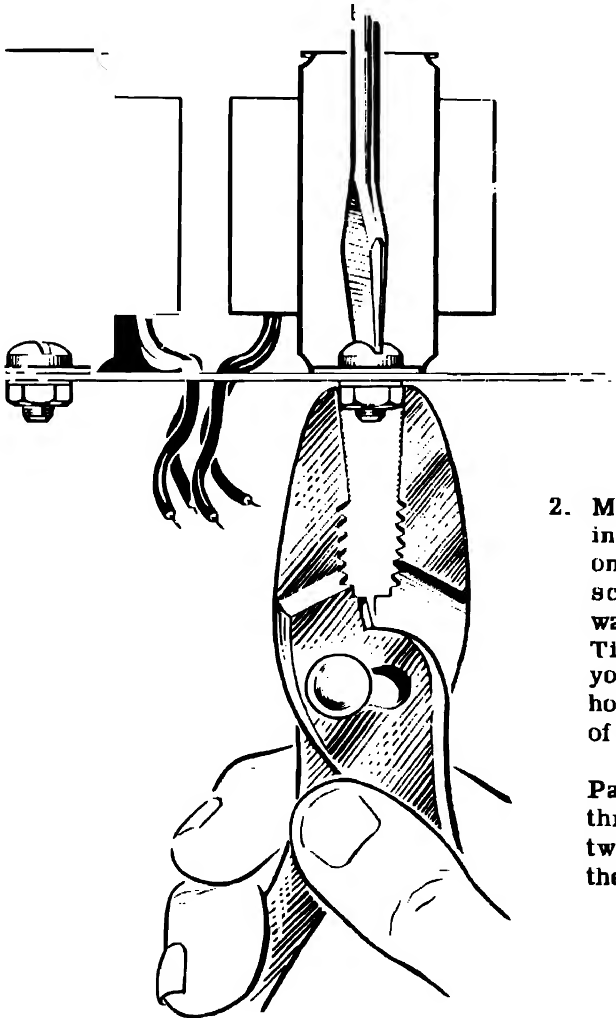
The illustration below shows where the filter chokes and the filter condenser are to be mounted. Detailed mounting instructions are given on the next sheet.



Experiment—Building the Filter Circuits

1. Using your fingers, remove the special locking nut from the electrolytic capacitor. Place the capacitor where shown in the layout diagram. Use the special locking nut to mount the capacitor. Hold the nut, and screw the capacitor into it. Tighten, using the method shown here.





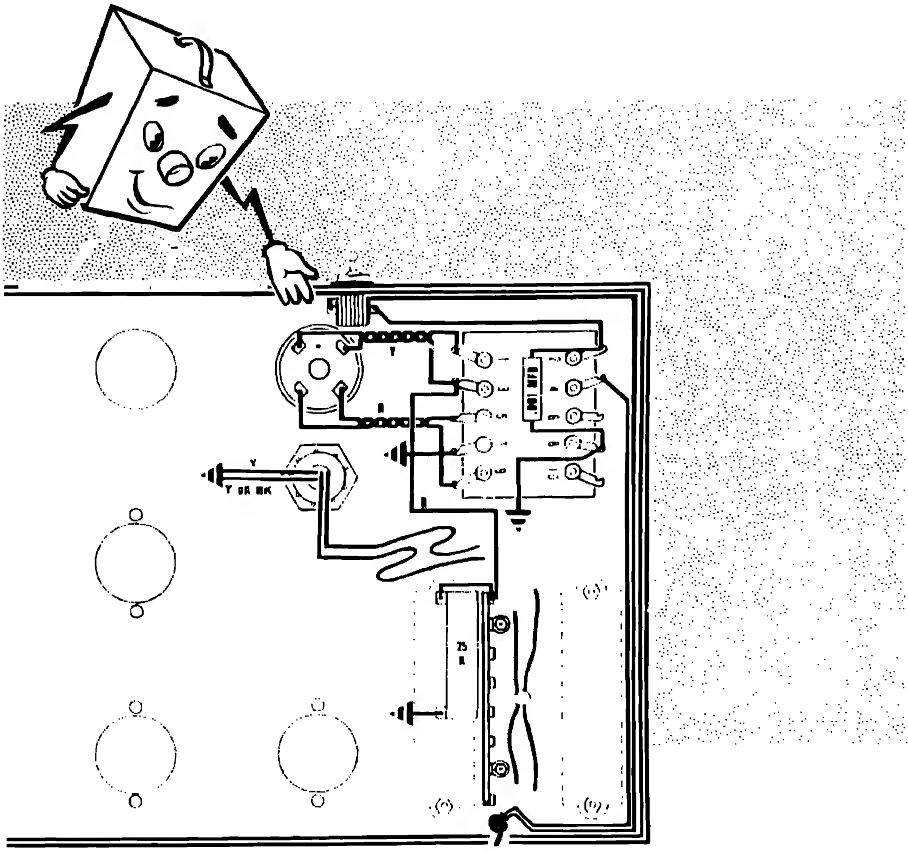
2. Mount the two filter chokes in their positions as shown on the layout diagram. Use screws, nuts and lockwashers as shown here. Tighten the screws with your screwdriver while holding the nut with a pair of pliers.

   Pass the choke leads through the chassis hole between the two chokes. See the illustration.

FILTER CIRCUITS

Experiment—Building the Filter Circuits (continued)

3. Connect the yellow or black negative leads of the electrolytic filter condenser to ground. Leave the blue or red positive leads unconnected as illustrated.



Your filter circuit is now set up for the experiments which will follow. The parts you have mounted on the chassis are all that you need to wire up a typical power supply. What you have on the chassis now is almost all you need in order to perform your experiments on filter circuits, voltage regulators, amplifiers, oscillators, transmitters and receivers. If you were to add a few tube sockets and supply heater voltages to those sockets you would have the basic chassis setup you require for all your future experiments in electronics. As long as you are doing wiring at this time suppose you finish up this work right now and save yourself time in the future.

FILTER CIRCUITS

Experiment—Building the Filter Circuits (continued)

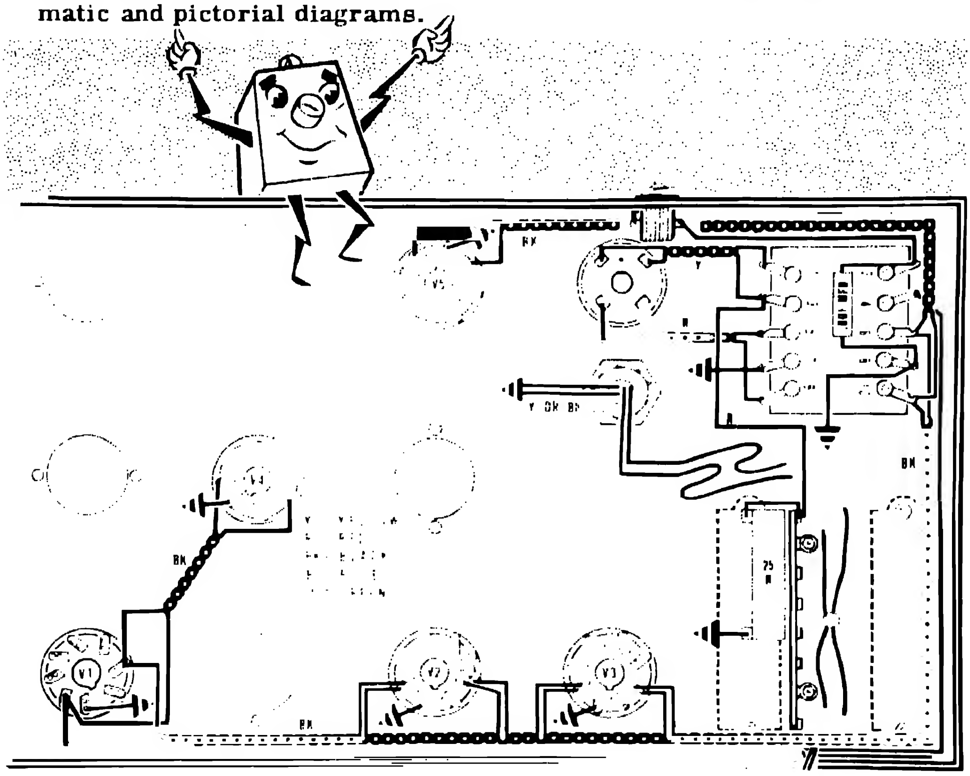
4. Mount the five octal (eight prong) sockets on the chassis in the positions shown below. Use the same procedure in mounting these sockets as you used to mount the four prong socket for the rectifier tube. Make sure that the keyway of each socket is turned to the position shown below.

5. Your next job is to wire up the tube sockets to a source of 6.3 volts AC for the heaters of the tubes that will eventually be put into these sockets. Transformer terminals 6 and 10 supply 6.3 volts AC, and the heaters of the new tubes will all be connected in parallel across this winding.

   Twist together two black wires until you have about two feet of twisted wire. Twisted wire kept close to the sides of the chassis tends to shield these wires and prevents them from radiating AC voltages which might be picked up by the circuits you will build in the future. Cut the twisted wire to the lengths required and put in the wiring as shown below.

6. Connect pin 1 of each octal tube socket to the closest point on the chassis, using bare wire. This connection supplies a ground for the shield of the metal tubes you will be using in the future.

7. The wiring is now complete. Clean out the chassis by removing all drops of solder and bits of wire, and check your work with the schematic and pictorial diagrams.



FILTER CIRCUITS

Demonstration—Observing Filter Circuit Wave Forms

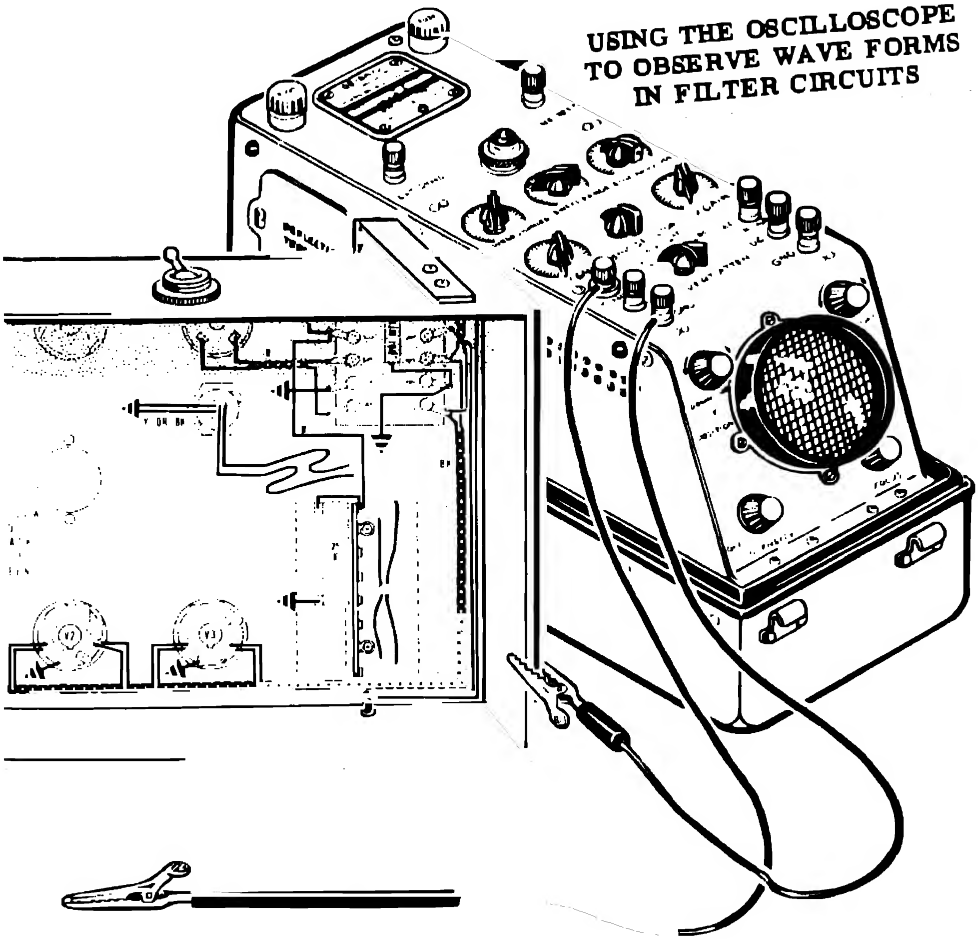
Now you are going to observe the action of the filter circuits as shown on the previous sheet. You will observe the wave forms for these filter circuits and compare the action of each type of filter to the others.

In addition to the chassis which now contains a full-wave rectifier circuit and the mounted filter components you will need the following:

1. An OS-8A/U oscilloscope and two test leads - one red, one black
2. A vacuum tube volt-ohmmeter and leads for each of its inputs

Note: These two items are also required for the experiment which follows.

The instructor first shows how the equipment is set up to observe filter circuit wave forms, then points out the connections required to make the different filter circuits. He also demonstrates the use and operation of the vacuum-tube volt-ohmmeter which you will use in performing the experiment on filter circuits.

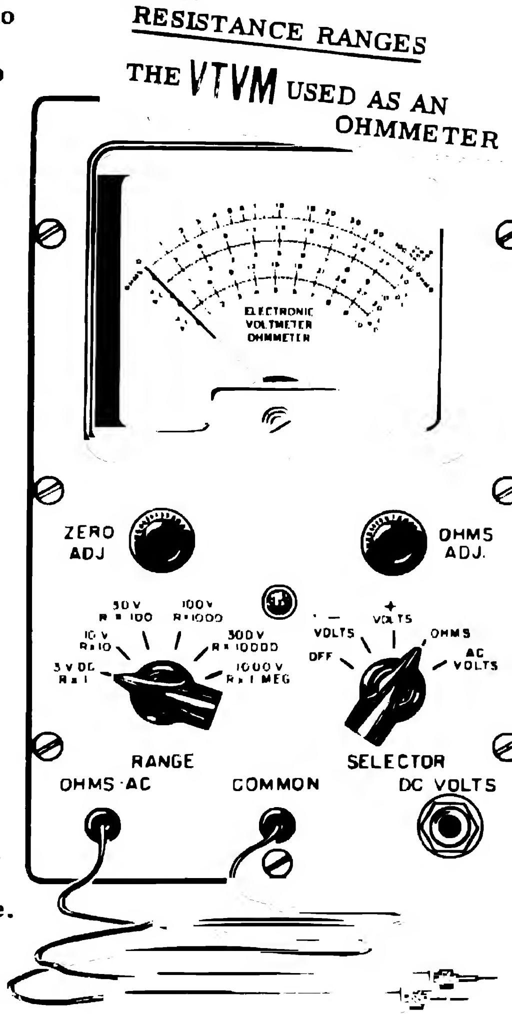


Demonstration—Use and Operation of the Vacuum Tube Volt-Ohmmeter

The vacuum-tube volt-ohmmeter is a very sensitive multimeter used to measure AC volts, DC volts and resistance. When used as a DC voltmeter or ohmmeter it requires only a negligible current flow for full scale deflection so that its effect on the circuit being tested is much less than that of an ordinary multimeter. On these ranges vacuum tubes in the meter make possible its use without drawing appreciable current from the circuit, but as an AC voltmeter the vacuum tubes are not used and the meter circuit is the same as that of other types of AC multimeters.

Since the meter uses vacuum tubes it requires a power supply which is built into the meter case and when the meter is used it is plugged into a 117 volt AC power outlet. The instructor next demonstrates the use of this meter as a DC voltmeter, ohmmeter and AC voltmeter. The meter operation as an ohmmeter is outlined below:

1. Plug the meter power cord into the AC power line outlet.
2. Turn the SELECTOR switch to the OHMS position.
3. Turn the RANGE switch to the desired ohms range.
4. Use the black test lead from the COMMON banana jack and the red test lead from the OHMS-AC banana jack.
5. Allow a few minutes for the tubes to heat—then zero the meter. The meter is zeroed by shorting together the leads and setting the meter pointer to zero on the ohms range (top scale on meter dial) by turning the ZERO ADJ. knob. Then with the leads open, turn the OHMS ADJ. knob to set the pointer to the maximum resistance reading on the ohms scale. Since the settings of the ZERO ADJ. and OHMS ADJ. knobs interact, this procedure should be repeated until the meter is correctly zeroed at both ends of the scale.
6. When the range selector is set at RX1 the resistance is read directly on the top meter scale. For other ohmmeter ranges the ohms scale reading is multiplied by the factor indicated on the range switch.



Demonstration—Use and Operation of the Vacuum Tube Volt-Ohmmeter (continued)

The steps used in operating the meter as a DC or AC voltmeter are outlined below:

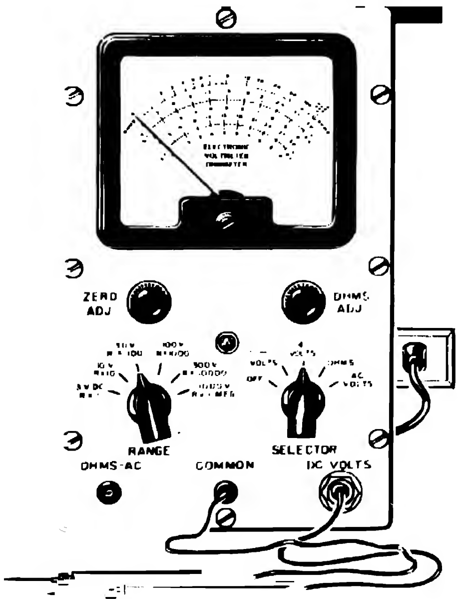
DC Voltage Ranges

1. Plug the meter power cord into the AC power line outlet.
2. Turn the SELECTOR switch to either the - VOLTS or + VOLTS position depending on the polarity of the DC voltage range.
3. Turn the RANGE switch to the desired voltage range.
4. Use the black test lead from the COMMON jack and the special test lead from the DC VOLTS jack.
5. Allow sufficient time for the tubes to heat properly, then turn the ZERO ADJ. knob to set the meter pointer at zero before making any measurements.
6. The middle meter scale is used for reading DC voltages.

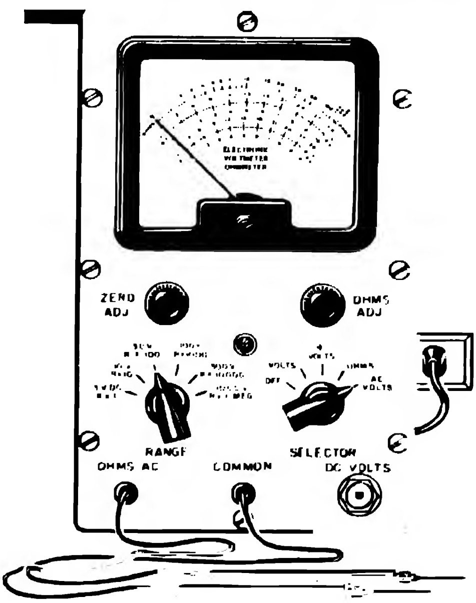
AC Voltage Ranges

1. Turn the SELECTOR switch to the AC VOLTS position.
2. Turn the range switch to the desired AC voltage range. (The 3 volt range is used only for DC volts.)
3. Use the meter test leads from the COMMON jack and the OHMS AC jack.
4. The bottom meter scale is used for reading AC voltages.

USING THE **VTVM** AS A DC VOLTMETER



USING THE **VTVM** AS AN AC VOLTMETER

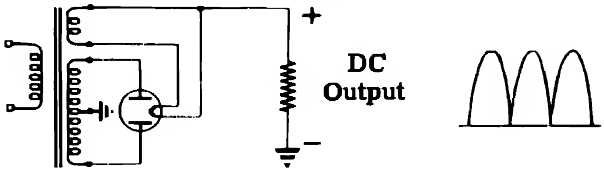


FILTER CIRCUITS

Experiment – Filter Circuit Wave Forms

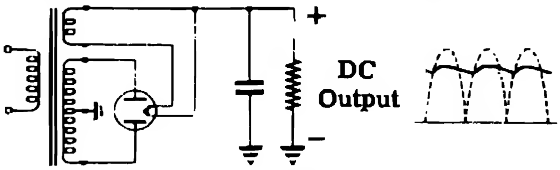
An oscilloscope can be used to observe the action of filter circuits in removing ripple voltage from the rectifier output. For a full-wave rectifier with no filter the wave form across the filter output is pulsating DC with each pulse shaped like a half cycle of AC. The ripple voltage is equal to the voltage of the AC component of the rectifier output.

UNFILTERED OUTPUT OF A FULL-WAVE RECTIFIER



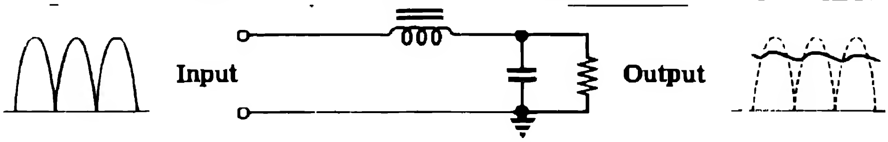
By connecting a filter condenser across the load resistor the wave form is changed and the amount of ripple voltage decreases. The action of the condenser prevents the output voltage from falling to zero. The ripple voltage wave form across the load resistor is shaped more like a sawtooth wave and has a much lower amplitude than that of the circuit with no filter.

EFFECT OF A FILTER CONDENSER ON THE OUTPUT WAVE FORMS



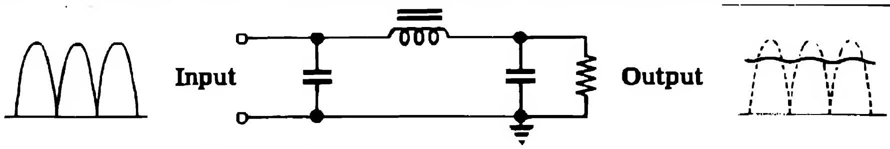
A single-section choke input filter further reduces the amplitude of the ripple voltage across the load resistor. Since the choke is connected between the rectifier and the filter condenser, the wave form of the input to the filter is that of an unfiltered full-wave rectifier circuit. This wave form can be used with the output wave form to determine the effect of the filter circuit on the ripple voltage.

WAVE FORMS FOR A SINGLE-SECTION CHOKE INPUT FILTER



The condenser input filter further reduces the output ripple voltage to a negligible value. The input condenser also reduces the ripple indicated at the input to the filter circuit since this condenser is connected directly across the rectifier output.

WAVE FORMS FOR A SINGLE-SECTION CONDENSER INPUT FILTER



Wave forms of a two-section choke input filter are similar to those of a single-section choke input filter except that the output ripple is reduced to a negligible value and usually too small to be observed on the oscilloscope screen.

FILTER CIRCUITS

Experiment—Observing the Rectifier Output Wave Form

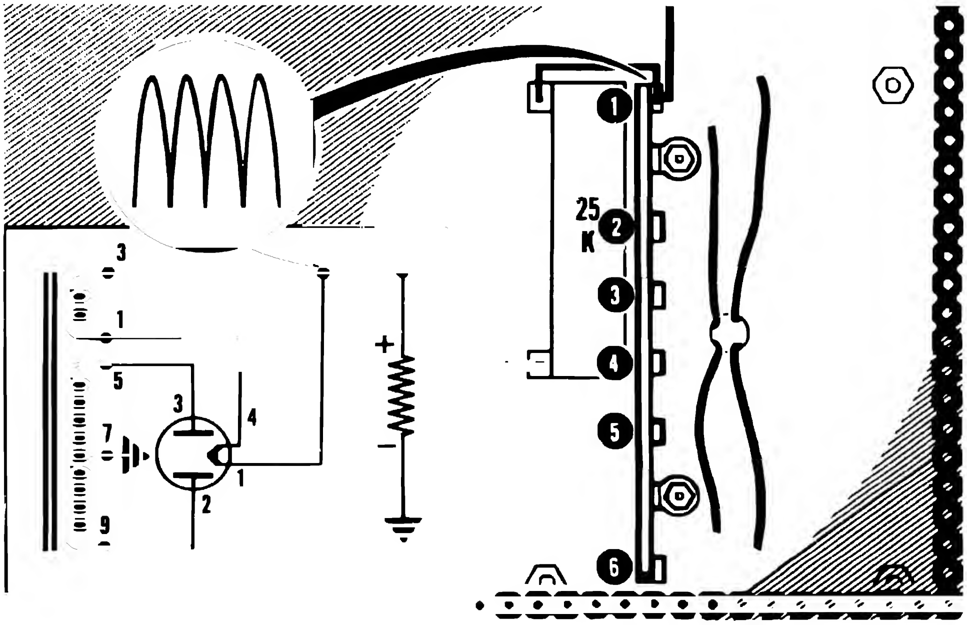
Now you are going to observe the wave forms of typical filter circuits and measure the DC output voltage of each type of filter. Before applying power to the full-wave rectifier circuit check the wiring for shorts and trace through the circuit to make certain it is the same as that shown in the circuit diagram.

As you observe the wave forms for the various filter circuits compare them to those previously shown. Although your results may not be exactly the same as those previously discussed, the overall effects observed should be the same.

Now set up your oscilloscope. You will use the unfiltered pulsating DC output of your full-wave rectifier as a reference wave form.

1. Connect your 'scope Y INPUT to lug 1 of the terminal strip nearest the transformer. Stop the wave form with the sweep controls and the SYNC AMPLITUDE control. Make sure that the SYNC SELECTOR switch is on INT. Adjust the Y GAIN control for a wave form 20 boxes high. You will leave the Y GAIN control at this setting throughout your filter experiments. Record the wave form on the first work sheet.

2. With your vacuum tube voltmeter, measure the DC voltage component at the point at which you took the wave form. Record this voltage in the space provided next to the first figure on your work sheet. This is the DC component of the unfiltered output voltage of your full-wave rectifier.



FILTER CIRCUITS

Experiment—Observing the Action of a Filter Condenser

In order to see how a condenser contributes to the filtering, do the following:

1. Connect one red or blue positive lead of the filter condenser to lug 1 of the terminal strip. The condenser is now in parallel with the 25K resistor to ground. Do NOT cut the condenser lead shorter.

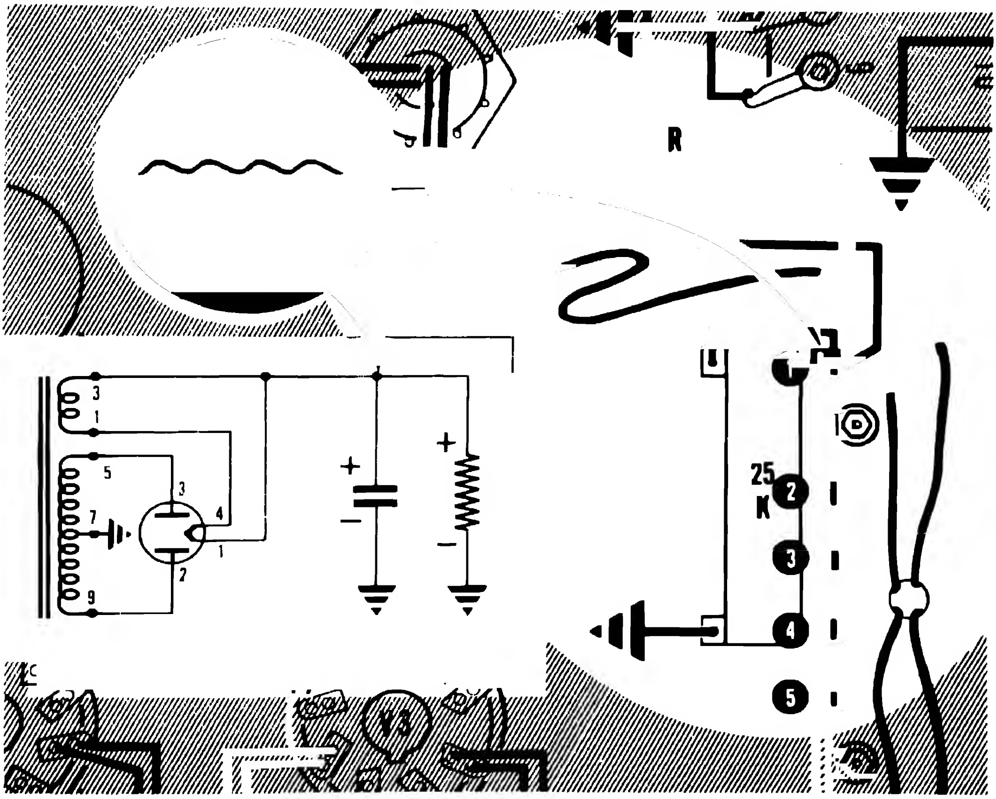
Check your work with an ohmmeter to see if any shorts exist.

Remember that you are working with a high voltage. Turn on your power supply.

2. Using your 'scope, take the wave form at the same point as before, taking care not to move the vertical gain control knob. Don't be surprised if the wave form is only one box high. Record it on your work sheet in the space opposite the second figure.

3. Using the 1,000-volt DC scale on your voltmeter, measure the voltage at the same point. Record this voltage on your work sheet.

Now compare the output voltage and wave form with the first figure on your work sheet. You have just proved that, when a condenser is placed across a rectifier output, the load voltage goes up. You can also see that the condenser has smoothed out the output considerably.



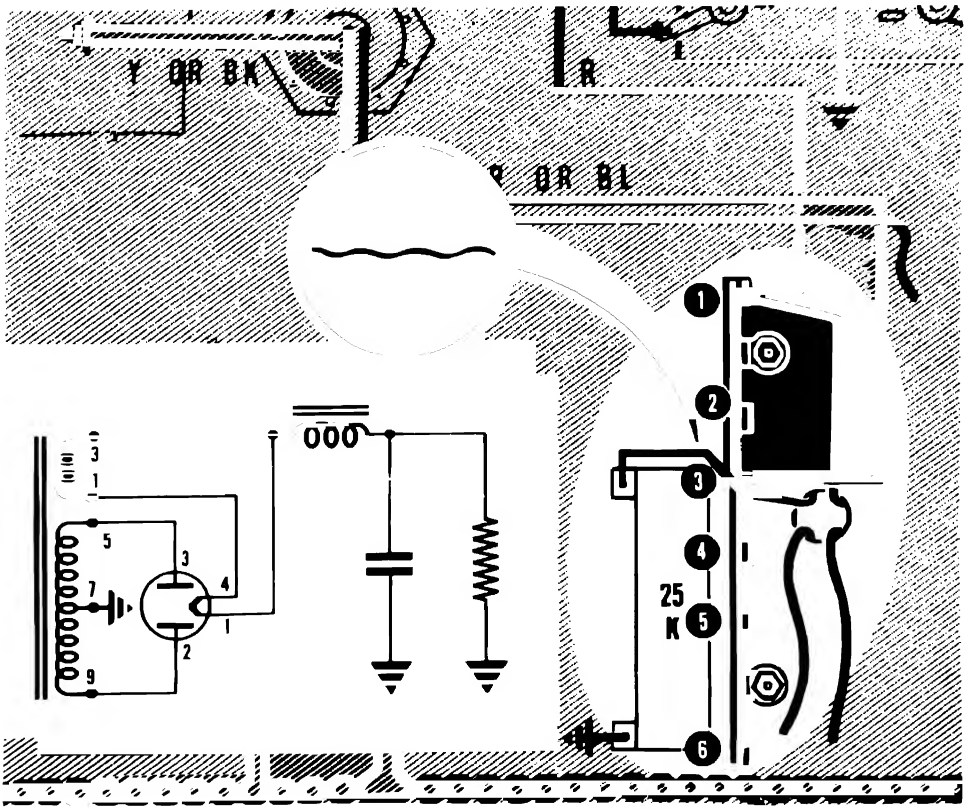
FILTER CIRCUITS

Experiment—The Single Section Choke Input Filter

Turn off your power supply.

In order to observe how the choke input filter contributes to filtering, do the following:

1. Disconnect the condenser lead and the 25K resistor from lug 1 on the terminal strip and connect them to lug 3.
2. Connect one of the leads from a filter choke to lug 3 on the terminal strip.
3. Connect the other lead from this choke to lug 1 where the rectifier cathode lead is already connected.
4. Check your circuit wiring for shorts. Apply power.
5. Take and record the wave form and DC voltage at the input to the choke input filter—lug 1.
6. Take and record the wave form and DC voltage across the 25K load. Take this at lug 3 of the terminal strip.



FILTER CIRCUITS

Experiment—The Condenser Input Filter

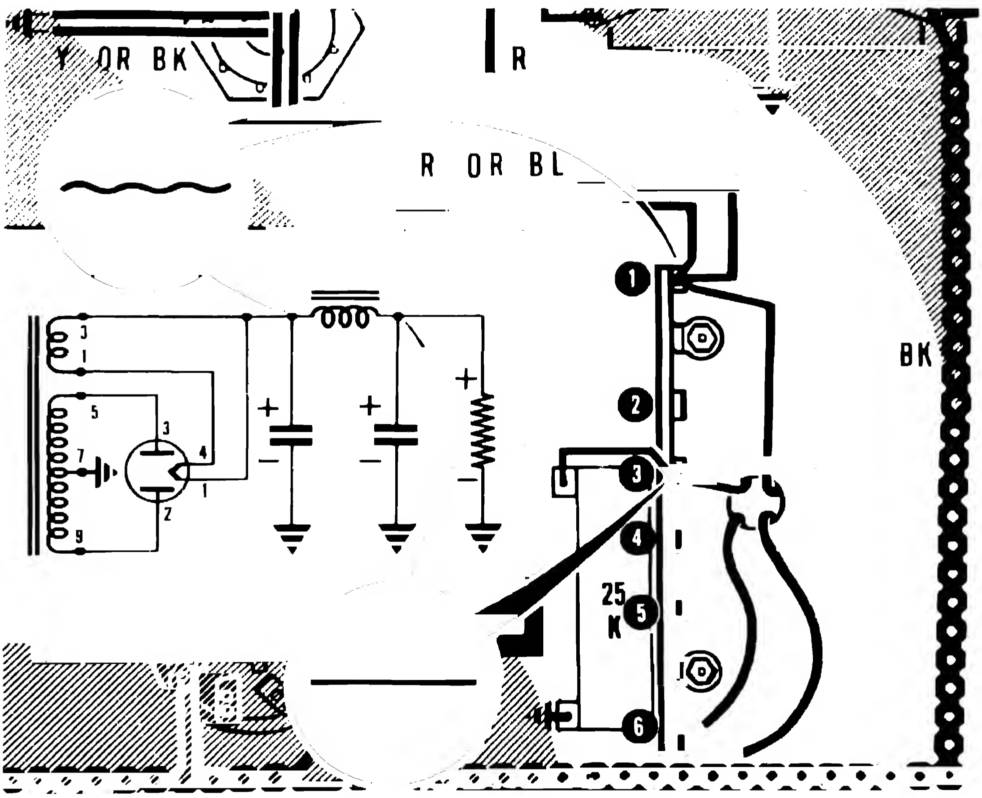
Another very common type of filter circuit is the condenser input filter, which differs from the choke input filter in that it has an additional condenser connected right across the output of the rectifier. The additional filter condenser improves the filtering and provides a higher output voltage than can be obtained with the choke input filter. The condenser input filter is used mostly in receiver power supplies and in cathode ray tube high-voltage power supplies.

To construct the condenser input filter:

1. Connect the free positive lead of the electrolytic condenser to terminal lug 1.

2. After you have checked your wiring, take two voltage and wave form readings. The first reading will be at the rectifier cathode. This point corresponds to lug 1 on the terminal strip.

3. The second reading will be across the 25K load at lug 3.



FILTER CIRCUITS

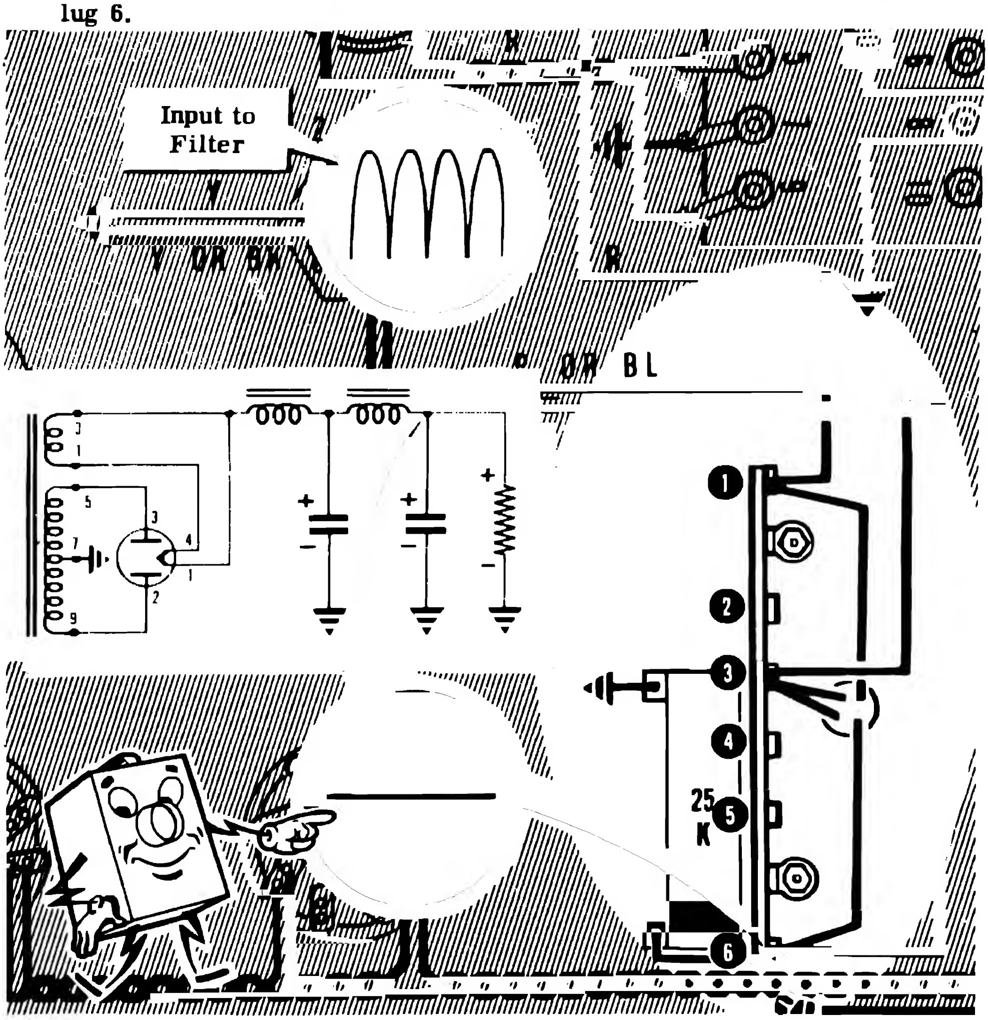
Experiment—The Double Section Choke Input Filter

This is the choke input filter circuit you will build into the power supply and use in all future experiments. It consists of the condenser input filter with an additional choke connected between the rectifier tube and the first filter condenser. The effect of the additional choke is improved filtering and a lower but more constant output voltage.

1. Remove the 25K resistor from lug 3 and the condenser lead from lug 1. Connect them to lug 6.

2. Connect one lead from the unused filter choke to lug 3 and connect the other lead to lug 6. Take the wave forms and voltages as you've done before. Record these on the fifth figure on your work sheets. The first reading will be taken at the input to the filter; take this at the terminal strip lug 1.

3. The second reading will be across the 25K load. This will be taken at lug 6.



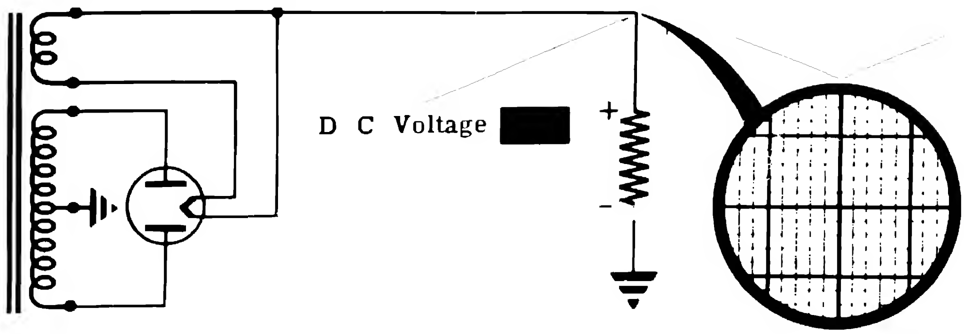
Filter Circuit Worksheets

So that you can compare the operation of the different filter circuits, enter your voltages and wave forms below.

FILTER WORK SHEET 1.

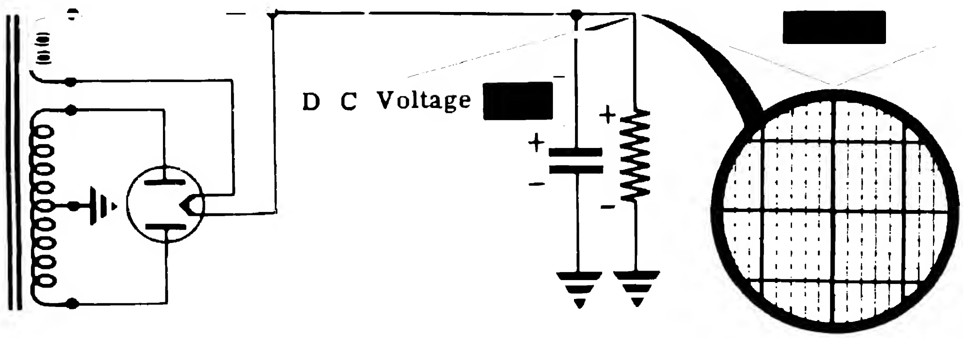
1. The Full-wave Rectifier

Boxes of Ripple



2. The Condenser

Boxes of Ripple



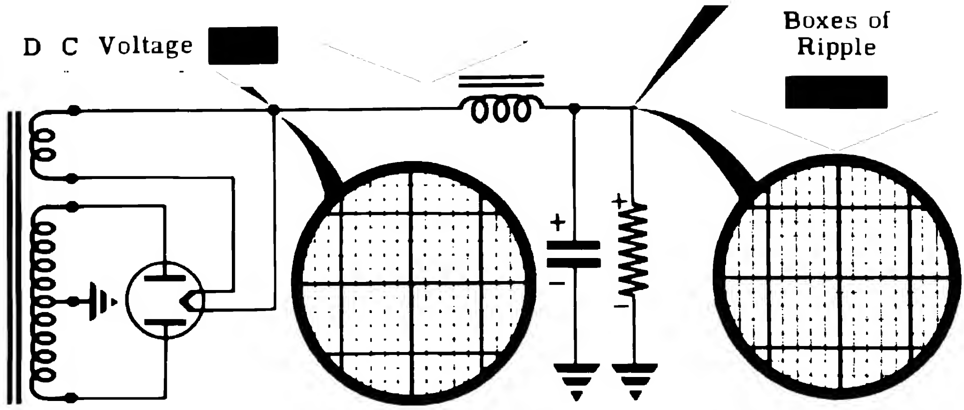
3. The Choke Input Filter

Boxes of Ripple

D C Voltage

Boxes of Ripple

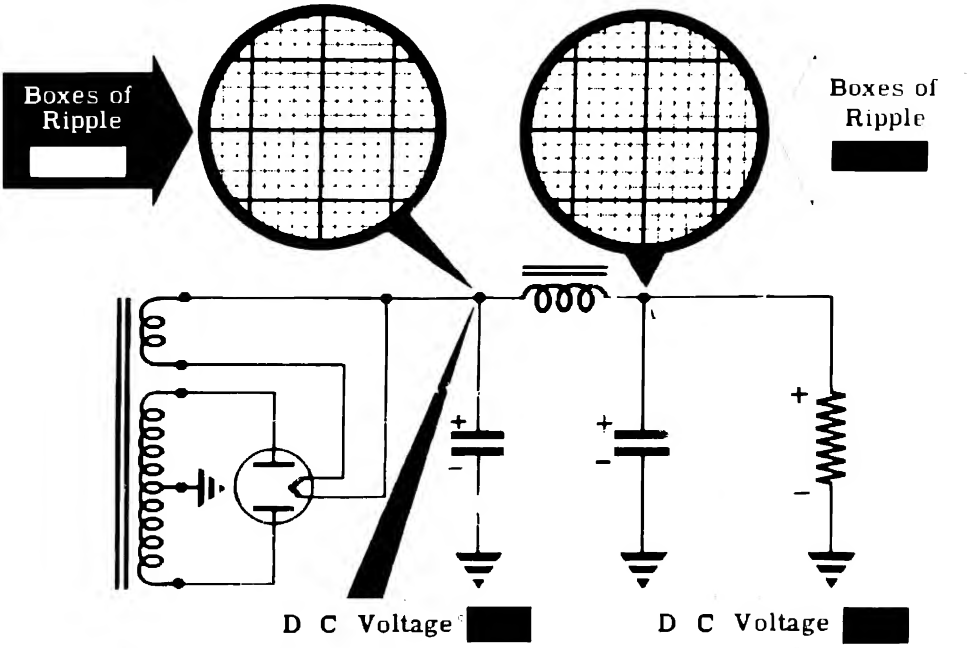
D C Voltage



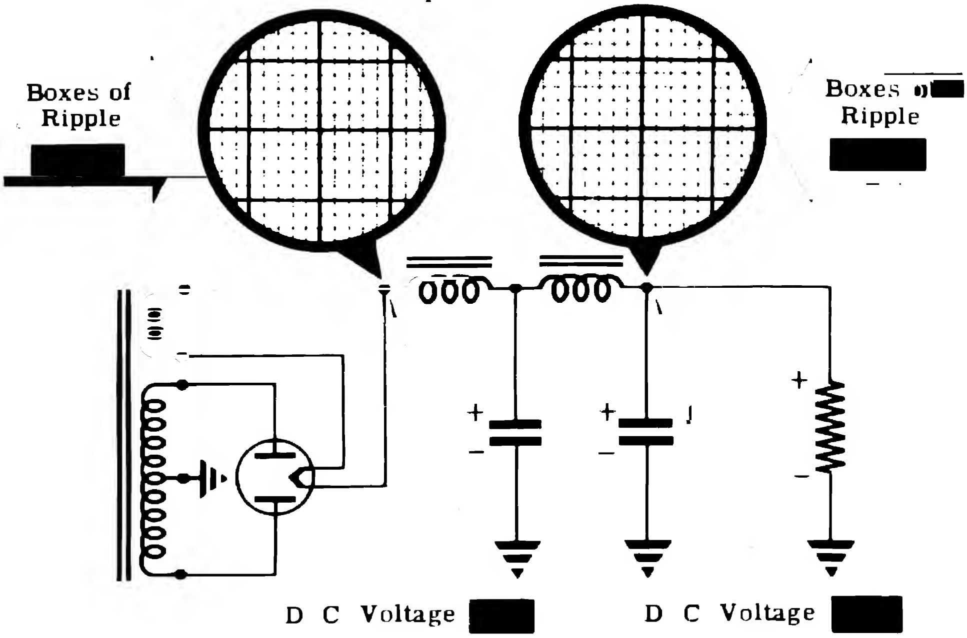
Filter Circuit Worksheets (continued)

FILTER WORK SHEET 2.

4. The Condenser Input Filter

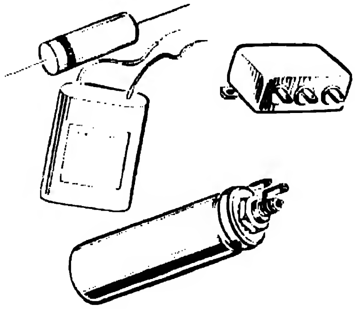


5. The Double-section Choke Input Filter

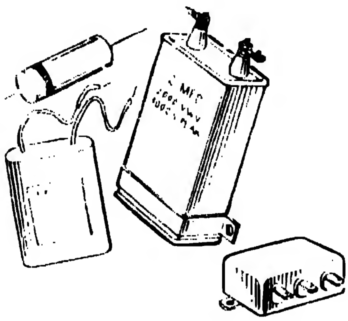


FILTER CIRCUITS

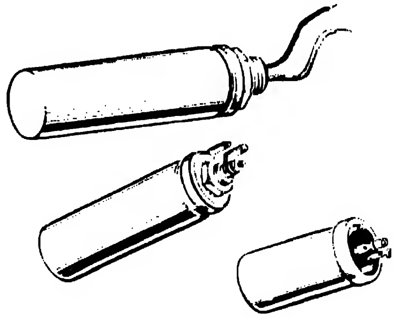
Review of Filter Circuits



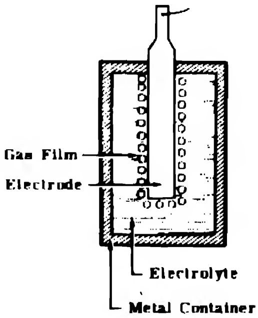
FILTER CAPACITORS — Capacitors used in power supplies to change the pulsating DC output of rectifiers into DC having a relatively slight variation in value. The condenser charges through the rectifier circuit and discharges through the load circuit to help maintain voltage applied to the load at a steady value.



PAPER FILTER CAPACITORS — Paper filter condensers are bulky and their value is usually limited to less than 10 mfd. They are not polarized and can be made to withstand very high voltages. There is no appreciable leakage across a paper filter condenser. Oil-impregnated paper condensers are used in high voltage filter circuits.

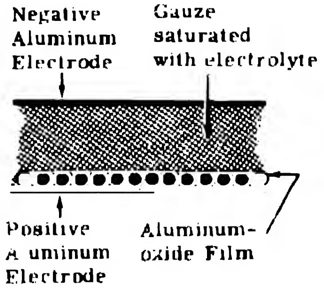


ELECTROLYTIC FILTER CAPACITORS — Electrolytics have a high value of capacitance as compared to a paper condenser of the same physical size. They are polarized and are normally constructed to operate at less than 600 volts. There is appreciable leakage across an electrolytic condenser but this effect is usually offset by their large values of capacitance. Electrolytics range in value from 1 to 1000 mfd.

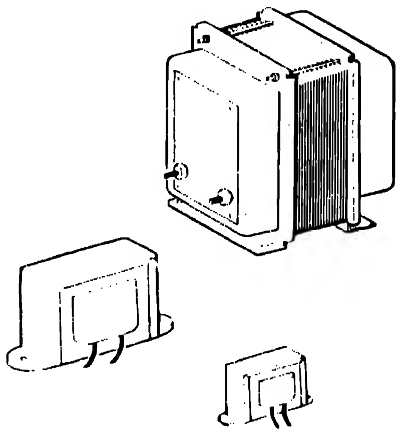


WET ELECTROLYTIC CAPACITOR — A condenser consisting of a metal electrode immersed in an electrolytic solution. The electrode and solution are the two condenser plates while an oxide film formed on the electrode is the dielectric. The dielectric film is formed by current flow from the electrolyte to the electrode.

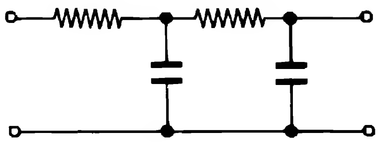
Review of Filter Circuits (continued)



DRY ELECTROLYTIC CONDENSERS — In a dry electrolytic condenser the electrolyte is a paste. Cloth which is impregnated with the paste is rolled between layers of metal foil which act as the condenser terminals. One metal foil is the positive plate and a film formed on its surface is the dielectric. The electrolyte paste is the negative condenser plate and its terminal connection is made through a layer of metal foil.



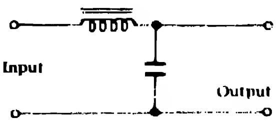
FILTER CHOKE — An iron-core inductance placed in series with the rectifier output. It opposes any change in current flow and reduces the amount of change in the pulsating DC output of the rectifier circuit.



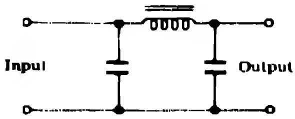
CHOKELESS POWER SUPPLY FILTER — A low current power supply filter circuit in which resistors are used in place of filter chokes. Resistors are used to save weight, space and cost.

Review of Filter Circuits (continued)

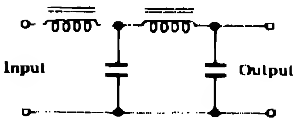
SINGLE-SECTION CHOKE INPUT FILTER — A filter circuit consisting of a filter choke connected in series with the rectifier output and a filter condenser connected across the output terminals. The output voltage ripple is between 3 and 10 percent of the DC output voltage.



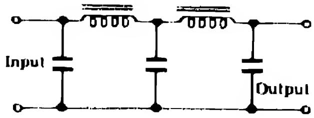
SINGLE-SECTION CONDENSER INPUT FILTER — A filter circuit consisting of a filter choke connected in series with the rectifier output and two filter condensers, one connected across the filter input and the other across the filter output terminals. The output voltage ripple is less than that of a single-section choke input filter and the voltage output is higher than that of a choke input filter.



TWO-SECTION CHOKE INPUT FILTER — A filter circuit consisting of two single-section choke input filters connected in series. The output ripple is a negligible value for most power supply applications.



TWO-SECTION CONDENSER INPUT FILTER — A two-section choke input filter with an additional filter condenser connected across the filter input terminals. The voltage output is increased as compared to a choke input filter and the ripple is reduced.

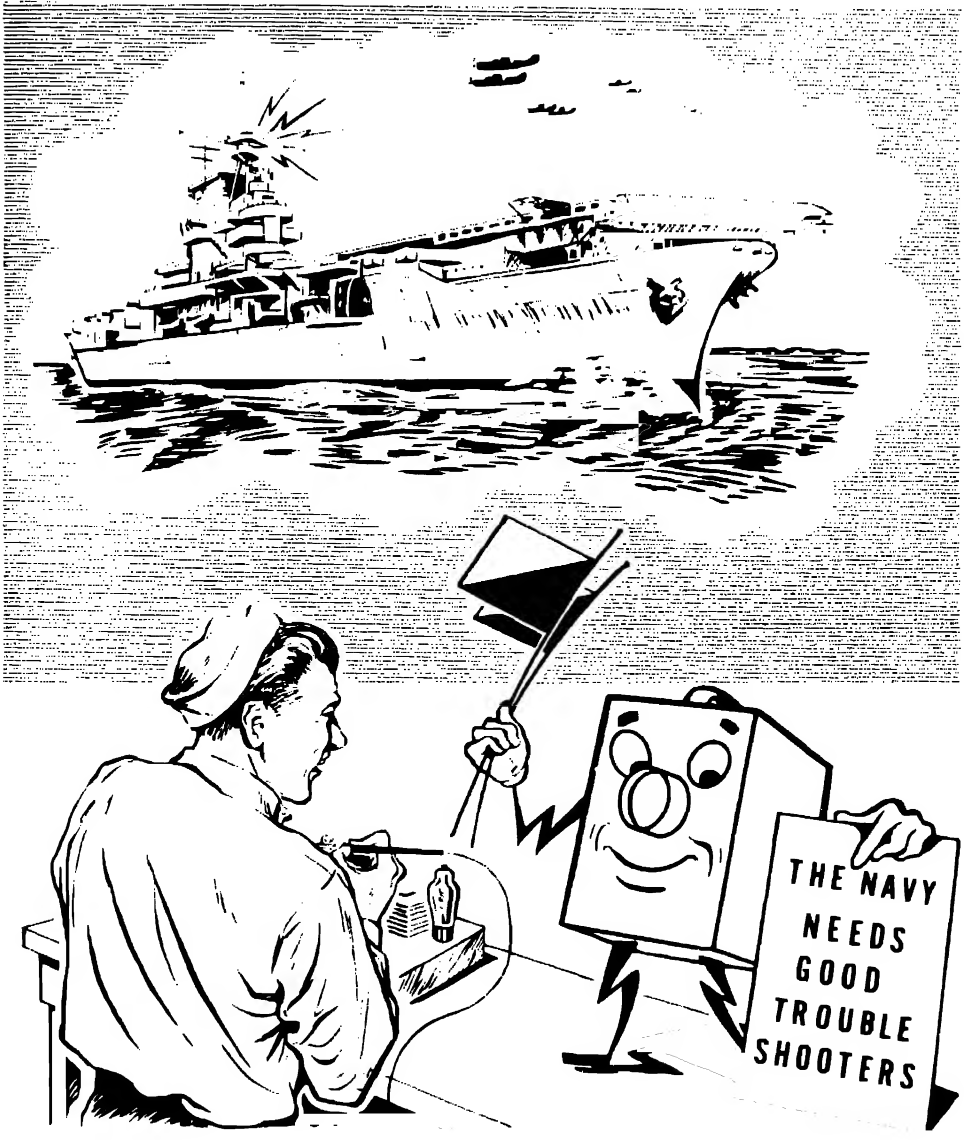


TROUBLESHOOTING POWER SUPPLIES

Importance of Troubleshooting

This is your first chance to see what you can do in the line of practical troubleshooting on power supplies. You will have some practice in troubleshooting simulated defects—defects that you know are there in the first place. Then you are going to get practice on troubles that someone else will put in, and you will not know what is wrong until you find it for yourself.

Again you must be reminded that an important part of your job will be to check, maintain and troubleshoot equipment. Many of the troubles found in power supplies are also found in other types of electronic equipment. Visual checks, signal tracing, voltage analysis and resistance analysis are all used in troubleshooting power supplies.



TROUBLESHOOTING POWER SUPPLIES

The Troubleshooting Method

Remember the procedure listed in the following paragraphs for finding troubles in power supplies. This procedure is not only good for your power supply, but for nearly every power supply you will find in Navy equipment.

Visual Checking

The importance of this step should not be underestimated—troubleshooters find many defects simply by looking and seeing them right away. When you are working with a simulated defect (one that you yourself have put in), the idea is to ignore the visible defect and try to find it by signal tracing. However, when you are working with a real trouble or one that is put in as a problem, you can often find it by inspection.

Visual checking does not take long—in about two minutes you should be able to see the trouble if it is the kind that can be seen. Learn the procedure which follows—you will be using it very often. It is good not only for power supplies but for any type of electronic gear.

A. Before you plug in the equipment look for:

(1) Loose Tubes—A tube that is not properly seated in its socket may not be making proper contact with the rest of the circuit. It may very well be a source of present or future trouble. Push the tube completely into place.

(2) Shorts—Any terminal or connection that is close to the chassis or to any other terminal should be examined for the possibility of a short. A short in any part of the power supply can cause considerable damage. Look for and remove any stray drops of solder, bits of wire, nuts or screws. It sometimes helps to shake the chassis and listen for any tell-tale rattle. Remember to correct any condition that may cause a short circuit—if it isn't causing trouble now, it may begin "acting up" in the future.

During the process of visual checking and signal tracing, you may find a terminal which the ohmmeter indicates is shorted to ground, but the cause of the short may not be immediately obvious. In order to locate the component causing the short, it is necessary to disconnect the parts one by one from the shorted terminal. Unsolder each suspected part from the terminal. As you disconnect each component, check the resistance from the terminal to ground. When the short disappears from the terminal, you have just removed the shorted component. Check the resistance from the detached end of the component to ground. Try to find the reason for the short. If it cannot be corrected because of a defect in the part, replace the part.

The Troubleshooting Method (continued)

(3) Discolored or Leaking Transformer—This is a sure sign that there is a short somewhere. Locate it. If the equipment has a fuse, find out why the fuse didn't blow out; too large a size may be installed or there may be a short across the fuse holder.

(4) Loose, Broken or Corroded Connections--Any connection that is not in good condition is a trouble spot. If it is not causing your present trouble, it will probably cause trouble in the future. Fix it.

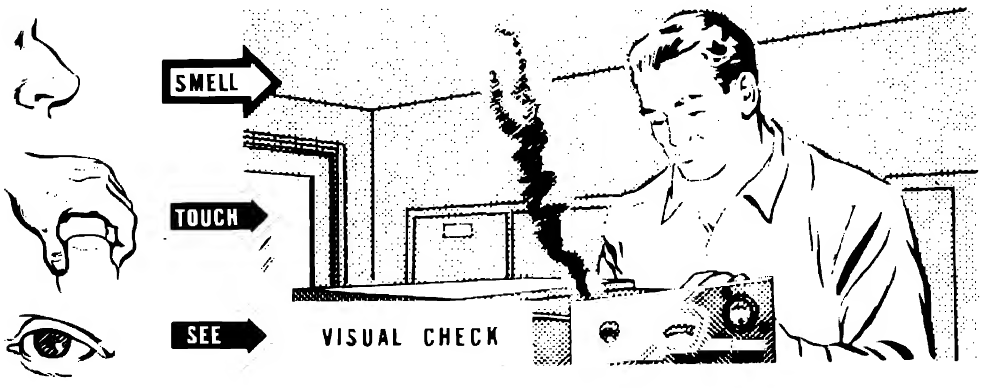
(5) Damaged Resistors or Condensers—A resistor that is discolored or charred has been subjected to an overload. An electrolytic condenser will show a whitish deposit at the seal around the terminals. Check for a short whenever you notice a damaged resistor or condenser. If there is no short, the trouble may be that the power supply has been overloaded in some way. Make a note to replace the part after signal tracing—there is no point in risking a new part until you have located the cause of the trouble.

B. Plug in the power supply and look for:

(1) Smoking Parts—If any part smokes or you hear any sound of boiling or sputtering, pull out the plug immediately. There is a short circuit somewhere that you have missed in your first inspection. Locate it with your ohmmeter—beginning in the neighborhood of the smoking part.

(2) Cold Tubes—Touch all the tubes on the equipment after you have allowed about two minutes for warming up. If a tube is cold, it is either burned out or there is a break in the heater connections and the tube is not receiving proper heater voltage. Remove the tube and connect your ohmmeter across the heater terminals to see whether or not the filament is open (reads almost infinite resistance). If the filament reads open, it is burned out—replace it with a good tube. If the filament reads a low resistance, it is all right—replace the tube and use an AC voltmeter to find the break in the path of the heater voltage from the transformer.

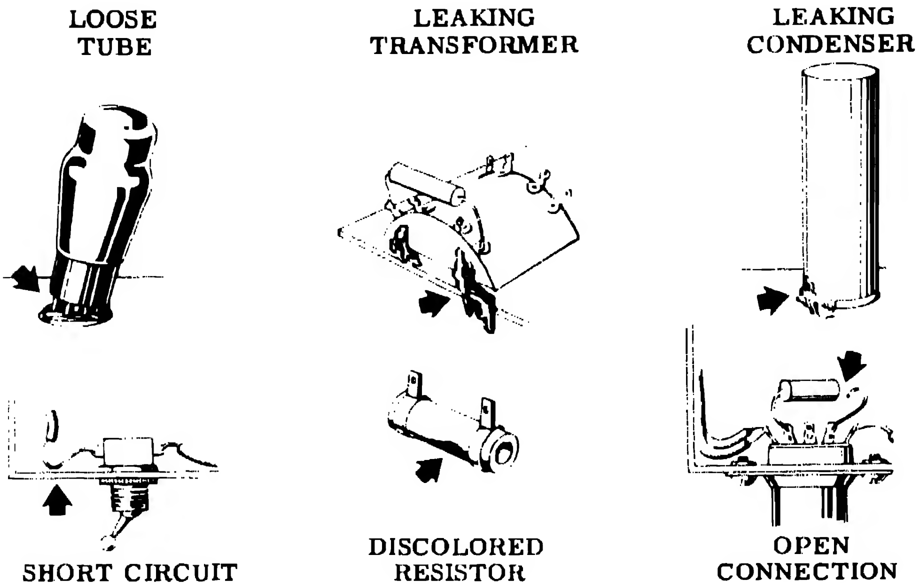
(3) Sparking—Tap or shake the chassis. If you see or hear sparking, you have located a loose connection or a short. Check and repair.



TROUBLESHOOTING POWER SUPPLIES

The Troubleshooting Method (continued)

If you have located and repaired any of the defects listed under visual checking, make a note of what you found and what you did to correct it. It is quite probable that you have found the trouble. However, a good repairman takes nothing for granted—you must prove to yourself that the equipment is operating properly and that there are no other troubles. Follow the procedure for signal tracing described in the following paragraphs.



If you have found none of the defects listed under visual checking, go ahead with the signal tracing procedure. Your trouble is probably of such a nature that it cannot be seen directly with your eye—it must be seen through the eye of the oscilloscope.

Signal Tracing

Tracing the AC signal through the equipment is the most rapid method of locating a trouble that cannot be found by visual checking, and it also serves as a check on any repairs you may have made. The idea is to trace the AC voltage through the transformer, see it change to pulsating DC at the rectifier tube filament and then see the pulsations smoothed out by the filter. The point where the signal stops or becomes distorted from what it should be is the place to look for the trouble.

Before you begin signal tracing, it would be a good idea to measure the DC voltage across the bleeder resistor (25,000 ohms). The DC output voltage should be in the neighborhood of 340 volts. If you have no DC output voltage, you will be looking for an open or a short in your signal tracing. If you have a low DC voltage you will be looking for a defective part, and you will have to keep your eyes open for the place where the signal becomes distorted.

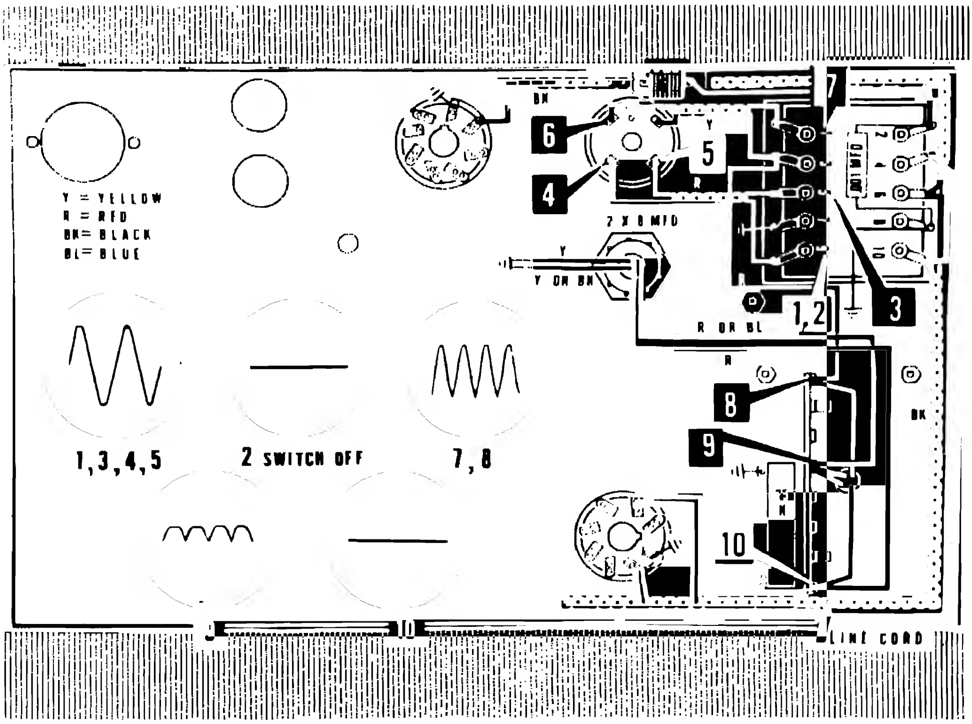
The Troubleshooting Method (continued)

Signal traving is done by observing the wave form at the input and output of each part of a circuit. It is the method used to localize troubles in circuits.

Let's review what each part of a good power supply does to the signal. The AC voltage is brought in from the power line by means of the line cord. This AC voltage is connected to the primary of the transformer through the ON-OFF switch. At the secondary winding of the transformer (Points 1 and 3) the 'scope shows you a picture of the stepped-up AC voltage developed across each half of the secondary winding—the picture is that of a complete sine wave. Each of the two stepped-up voltages is connected between ground and one of the two plates of the rectifier tube. At the two rectifier plates (Points 4 and 5) there is still no change in the shape of the stepped-up AC voltage—the 'scope picture still shows a complete sine wave.

However, when you look at the 'scope picture for Point 7 (the voltage at the rectifier heater) you see the wave shape for pulsating direct current. This pulsating DC is fed through the first choke and filter condenser which remove a large part of the ripple or "hum," as shown by the picture for Point 9 with the 'scope vertical gain control turned to maximum. Finally the DC voltage is fed through the second choke and filter condenser which removes nearly all of the remaining hum—see the picture for Point 10, which shows almost no visible hum with the 'scope vertical gain control turned all the way up. You now have almost pure DC.

No matter what power supplies you may run into in the future, they all do the same thing—they change AC voltage into DC voltage.



TROUBLESHOOTING POWER SUPPLIES

The Advantages of Signal Tracing

A. The point-to-point system of voltage and resistance measurement is no longer practical with present day electronic equipment because:

1. The number of points to be tested has increased tremendously.

2. Operating voltages and resistances may be normal and yet the equipment may be inoperative because:

   a. Misalignment of tuned circuits and coupling circuits (due to age, moisture, vibration, etc.) ordinarily have no effect on operating voltages and resistances.

   b. Many types of automatic control voltages (automatic frequency control, automatic volume control, automatic noise suppression, etc.) and diode detection depend upon a proper signal condition for their operation. These conditions are not apparent in static testing.

   c. Defective tubes may have proper voltages and may be "accepted" by a tube tester—but do not function in the circuit.

B. Signal tracing has the following advantages:

1. The number of points to be tested is cut down tremendously since an entire section of the equipment containing dozens or even hundreds of static checking points (entire audio amplifier, entire I. F. amplifier, entire sawtooth generator, etc.) may be tested at once by inserting a signal at the input and observing the signal at the output. As a result the general area of trouble may be identified almost immediately for further testing.

2. Misalignment of tuned circuits and coupling circuits can be recognized by examining for lack of signal or distorted signal.

3. Tubes that are <u>functionally</u> defective may be rapidly located by comparing the input and output.

4. Automatic control voltages and diode detection may be observed under actual or simulated operating conditions.

5. Due to the fact that the trouble may be rapidly localized, the troubleshooter can devote the major part of his efforts to effective work in finding the exact part which is defective.

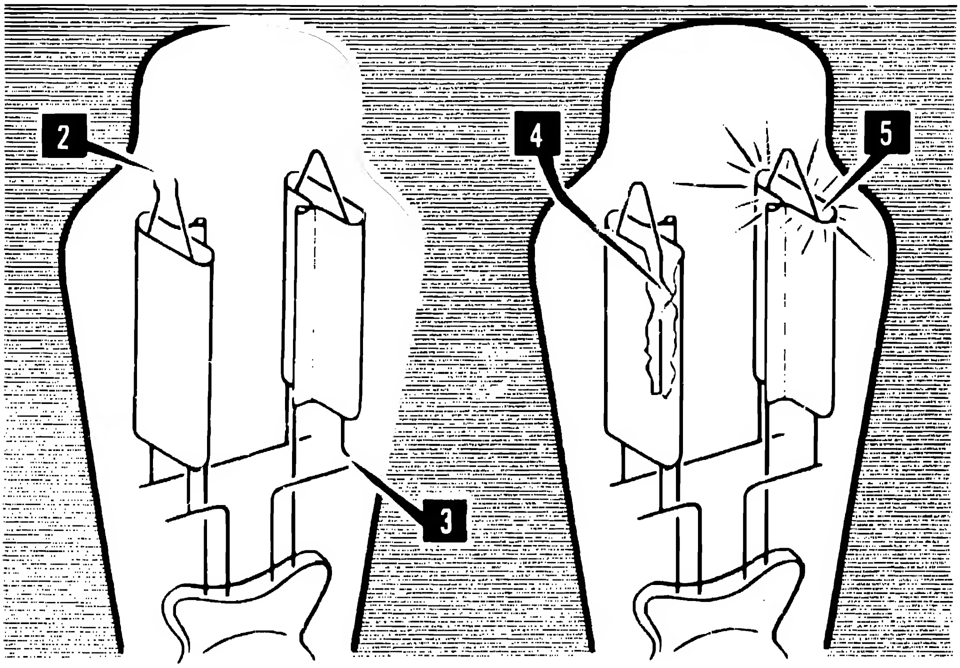
6. Once trained in the <u>method</u> of signal tracing, the troubleshooter can effectively test any type of equipment with which he is familiar even though he has had no experience with that particular model.

Conclusion: The advantages of signal tracing are its speed, its universal application and its positive identification. It is a functional test of a circuit under conditions of actual use.

TROUBLESHOOTING POWER SUPPLIES

Tube Troubles

Of course, the symptoms of tube trouble will vary with every type of circuit and each type of tube. However, the troubles that can happen to a tube are common to every tube. Here are the five possible tube troubles which you must keep in mind. The meaning of each trouble will be clear by the time you end the study of vacuum tubes, even though you may not quite understand it now.



1. The filament, after long service, may be unable to emit as many electrons as are required for proper operations.
2. The filament may burn out.
3. A tube element—the plate, for instance—may break its connection with the tube base pin.
4. Two elements, such as filament and plate, may short together.
5. The tube may become gassy.

The symptoms you will come across in signal tracing will be many and varied. You will need to combine your "know-how" of the circuit and your knowledge of these five possible tube troubles to determine if the tube could in some way be causing the symptoms. If the tube is suspected of causing trouble, then you will need to try another tube in its place or check it on a tube tester; but remember, the final check of whether or not the old tube was bad is whether or not the equipment works properly when a good tube is put in its place. Therefore, putting in a good tube and trying out the equipment is the best check.

TROUBLESHOOTING POWER SUPPLIES

Transformer and Choke Troubles

As you already know, the transformer and choke are quite similar in construction. Therefore, it is no coincidence that the basic troubles that can happen to them are the same.

1. A winding can open up.

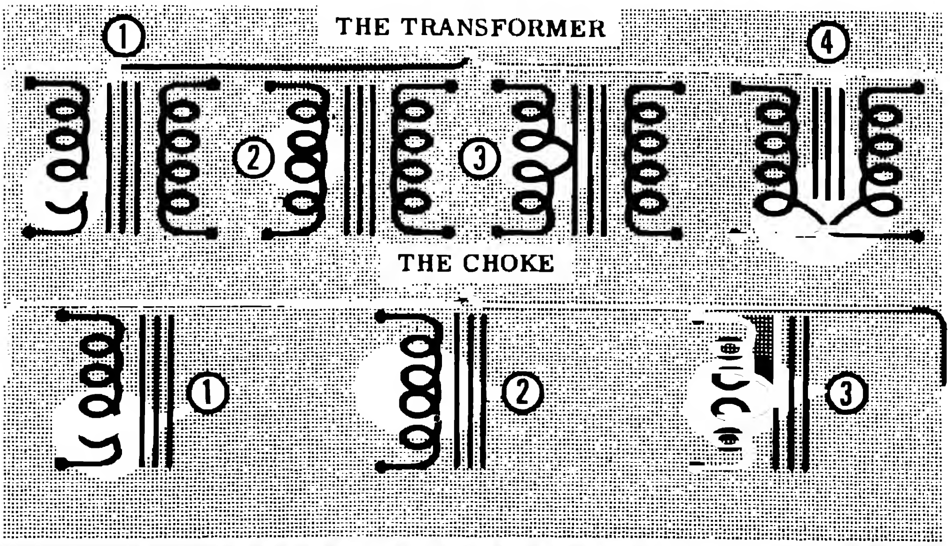
2. Two or more turns of one winding can short together.

3. A winding can short to the casing which is usually grounded.

4. Two windings can short together. This trouble is, of course, possible only in transformers.

As with the tube, the symptoms in the circuit of these troubles will vary with the type of circuit. However, when you have once decided that one of these four possible troubles could be causing the symptoms, there are definite steps to take. If you surmise that there is an open winding or windings shorted together or to ground, an ohmmeter continuity check will turn up the trouble. If the turns of a winding are shorted together, you may not be able to detect a difference in winding resistance. Therefore, You would need to connect a good transformer in place of the old one and see if the symptoms were eliminated, but keep this in mind: transformers are difficult to replace. Make absolutely sure that the trouble is not elsewhere in the circuit before changing the transformer.

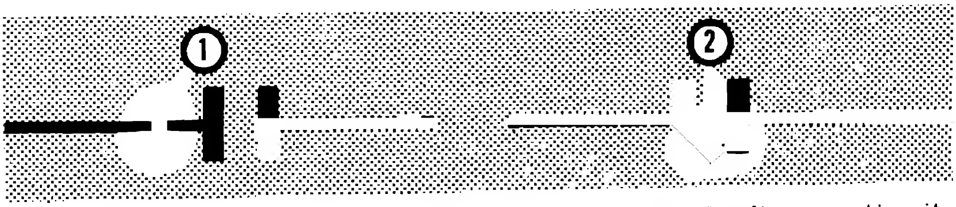
Occasionally, the shorts will not appear except when the operating voltages are applied to the transformer. In this case you might find the trouble with a megger, an instrument which applies a high voltage as it reads resistance. Your instructor will tell you more about this.



Condenser and Resistor Troubles

Just two things can happen to a condenser:

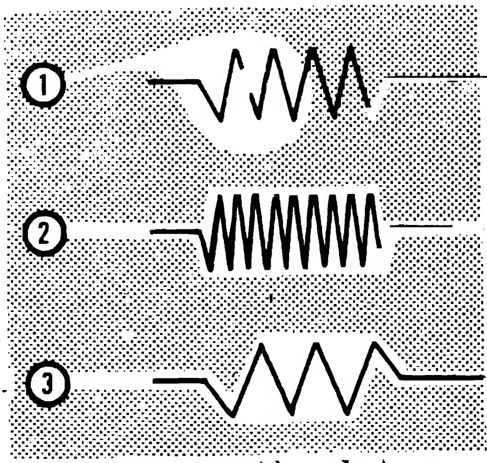
1. It may open up—removing the condenser completely from the circuit.
2. It may develop an internal short circuit. This means that it begins to pass current as though it were a resistor or a direct short.



You may check a condenser, suspected of being open, by disconnecting it from the circuit and checking it with a capacity meter. You can check one suspected of being leaky with an ohmmeter—if it reads less than 500K, it definitely is bad. However, condenser troubles are difficult to find since they may appear intermittently or only under operating voltages. Therefore, the best check of a doubtful condenser is to replace it with one known to be good. If this restores proper operation, the fault was in the condenser.

Resistor troubles are the simplest of the lot but, like the rest, you must keep them in mind all the time.

1. A resistor can open up.
2. A resistor can increase in value.
3. A resistor can decrease in value.



You know already how to check possible resistor troubles. Just use an ohmmeter after making sure that there is no parallel circuit connected across the resistor you wish to measure. When you are in doubt or are sure that there is a parallel circuit, disconnect one end of the resistor before measuring it. The ohmmeter check will usually be adequate. However, never forget that occasionally intermittent troubles may develop in resistors as well as any other electronic part, so that the final proof that a resistor is bad is when another resistor in its place makes the equipment operate satisfactorily.

TROUBLESHOOTING POWER SUPPLIES

Examples of Troubleshooting

Now that you know what to do, let's go through some typical troubleshooting problems. Pay careful attention, because you will carry out the same procedures in the equipment that follows.

Example No. 1

First appearances

There is a tag attached to the power supply which says "No Output." When you are lucky enough to find a complaint tag attached to the defective equipment, pay attention to what it says, because it may give you a valuable hint as to what is wrong. From first appearances, it seems that you will be looking for an open circuit or a short to ground.

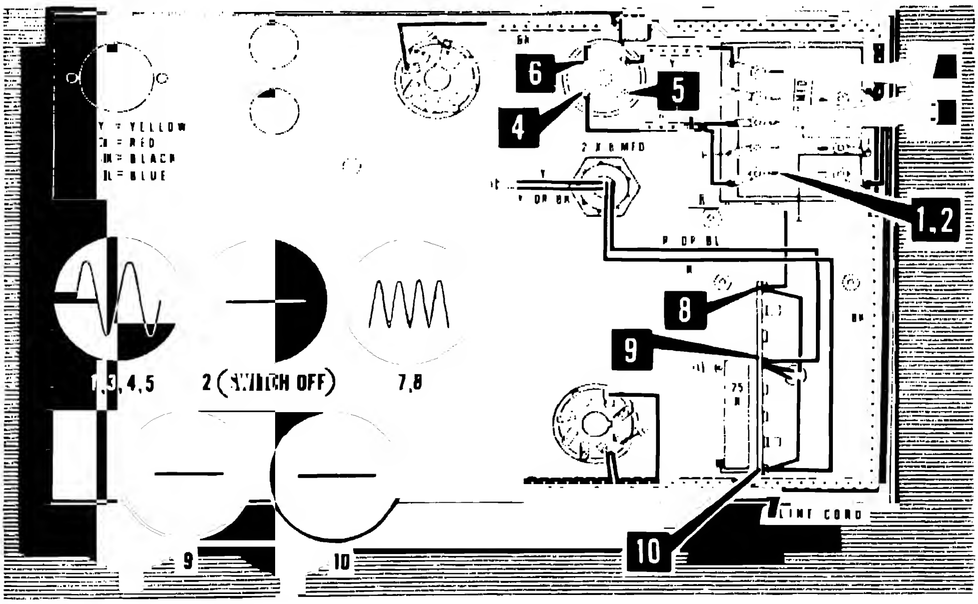
Visual inspection

You notice that Point 9 on the terminal strip has a very loose connection where the lead from the first choke comes to the first filter condenser. You tighten and resolder the connection and make a note of what you did. There is a very fair possibility that you have found the trouble.

Signal tracing

1. You plug in the power supply line cord and connect the DC voltmeter across the bleeder resistor. There is no output. The loose connection was not the only cause of trouble.

2. Using the oscilloscope, you trace the signal from the transformer secondary, through the rectifier tube and up to the first choke—the signal is completely normal up to Point 8.



Examples of Troubleshooting (continued)

3. When you reach Point 9, which is the output of the first choke, the signal is gone. This could only mean an open between Points 8 and 9. There is little chance of a short to ground, since the transformer is not overheated and there is no loss in signal height as you approach the choke from the preceding test points.

4. An ohmmeter check will show whether you are right or wrong. You pull out the line cord and short Points 9 and 10 to ground with an insulated handled screwdriver to make sure that there is no residual charge on the condensers which might possibly damage the ohmmeter. You connect the ohmmeter across Points 8 and 9 and read infinite ohms. You disconnect the first choke from terminals 8 and 9 and connect the ohmmeter across the ends of the leads—the ohmmeter still reads ∞. The first choke definitely has a break in it.

5. You temporarily patch a replacement choke across terminals 8 and 9 and turn on the power supply. The signal now can be traced through the entire circuit without any variation from what it should be, and the DC voltmeter shows a normal output. The trouble was a damaged choke. It should be replaced and a final check made both with 'scope and DC voltmeter.

6. Here is the proof that the choke was the cause of the trouble:

   A. The signal was present at the input to the first choke (Point 8) but there was no signal at the output of the first choke (Point 9).

   B. An ohmmeter check across the suspected choke indicated that it was open.

   C. Replacing the suspected choke with a good one restored normal operation to the power supply.

Example No. 2

First appearances and visual inspection

There is no complaint tag attached to the power supply. Nothing appears to be wrong.

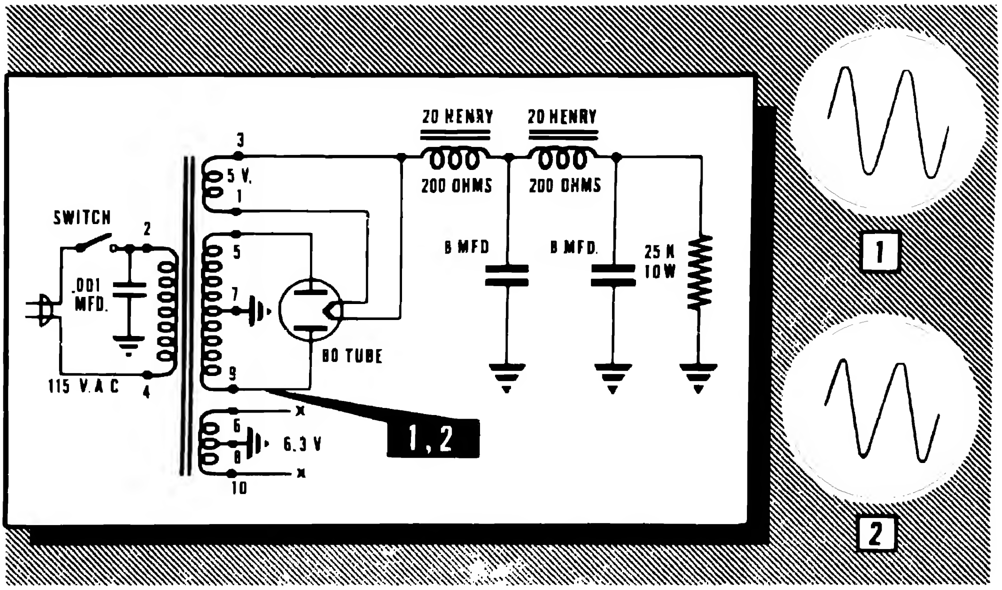
Signal tracing

1. A DC voltmeter connected across the bleeder resistor indicates that the output voltage is correct. Perhaps the defect is excessive hum. You connect the 'scope across the bleeder resistor and you can barely see any ripple, even with the Y GAIN control turned all the way up. The trouble is not excessive hum.

2. Perhaps the defect is an open bleeder resistor. You pull out the power supply line cord and short the high voltage ends of the filter condenser (Points 9 and 10) to ground so as not to damage your ohmmeter. There is barely any spark, showing that the bleeder resistor has drained off most of the charge in a few moments. An ohmmeter check shows that there is nothing wrong with the resistor.

TROUBLESHOOTING POWER SUPPLIES

Examples of Troubleshooting (continued)



3. There is apparently nothing at all wrong but, before checking the power supply as O.K., you decide to trace the signal through the circuit. Point 1 (the output of one-half the transformer secondary winding) shows a good sine wave. When you shut off the power switch for Point 2, the sine wave does not disappear. Something is wrong with the switch.

4. An ohmmeter check will show whether or not the switch is shorted. You pull out the line cord and short the high voltage ends (Points 9 and 10) of the electrolytic condensers to ground, using an insulated handled screwdriver. Connect the ohmmeter across the switch terminals— the scale reads zero ohms. Throw the switch and a short is still there. Since there is nothing visibly wrong with the switch, there is an internal defect and it must be replaced.

5. Replace the switch and recheck the output across the bleeder resistor with the DC voltmeter. The DC voltmeter reads zero when the switch is OFF and the proper value when the switch is ON. A check with the 'scope shows good output with very little hum. The trouble has been repaired.

6. It took five steps to find a very simple trouble but, as there was no complaint tag, the procedure you followed was a logical one.

7. Here is the proof that the switch was the cause of the trouble:

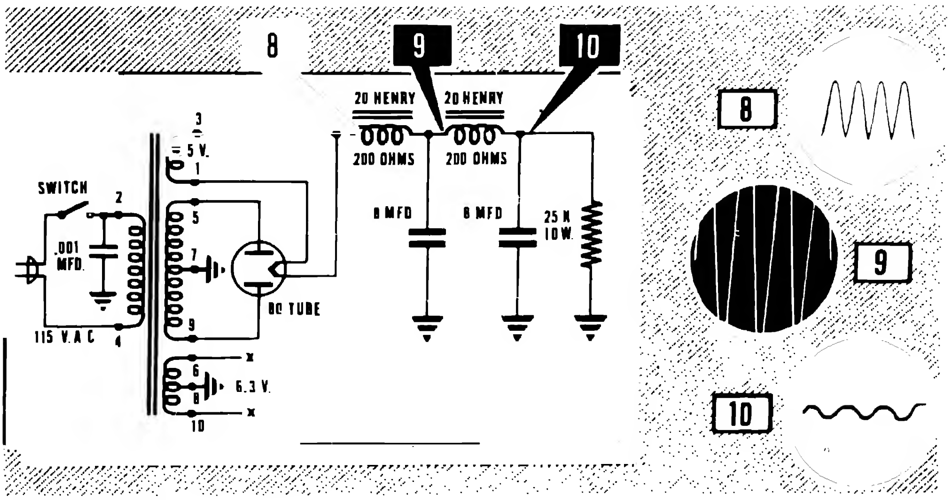
   A. Visual checks, output voltage checks, hum checks and other checks indicate nothing wrong.

   B. A signal tracing check indicated that the signal did not disappear when the line switch was turned OFF.

   C. An ohmmeter check indicated an internal short in the switch.

TROUBLESHOOTING POWER SUPPLIES

Examples of Troubleshooting (continued)



Example No. 3

First appearances

There is no complaint tag attached to the power supply.

Visual inspection

There are several slightly corroded connections on the terminal strip to which the chokes and filter condensers are connected. You resolder them and make a note of what you have done.

Signal tracing

1. You connect a DC voltmeter across the 25K bleeder resistor, after plugging in the power supply and turning on the switch. The voltage is about 100 volts DC, which is definitely too low.

2. You connect your 'scope across the bleeder resistor (Point 10) and you notice that there is about 1-1/2 boxes of ripple on the screen with the vertical gain control set at maximum. This is excessive hum and is probably the reason the power supply was sent for repairs.

3. The logical place to look for excessive hum is in the filter section. You connect the 'scope to Point 8, which is the input to the first choke. The signal shows full-wave rectified DC from the rectifier heater, and there is nothing wrong with it.

4. The next thing to check is Point 9, which is the output of the first choke and the input to the first filter condenser. You observe a great drop in ripple as compared to Point 8; but when you turn up the 'scope Y GAIN control to maximum, the ripple is higher than the full height of the screen. There is something wrong with the first section of the filter and a recheck of Point 10 would not be conclusive until the possible defects in the first choke and filter condenser have been investigated.

Examples of Troubleshooting (continued)

5. It is possible that a large number of turns have been shorted out of the choke and an ohmmeter check from Points 8 to 9 would then read less than 200 ohms, but this would not cause a drop in DC voltage. It is also possible that there is a partiai short to ground inside the choke or the electrolytic condenser. You pull out the line cord and discharge the condensers with an insulated handled screwdriver. An ohmmeter check from Point 8 to ground reads about 10,000 ohms which bears out the second possibility.

6. You unsolder the condenser lead from Point 8 and the low resistance to ground disappears from Point 8, but is still present when the resistance is measured from the detached end of the condenser. This indicates a leaky condenser. You detach the other condenser lead from Point 10 and patch a good condenser into the circuit for a check.

7. A 'scope check at Point 10 shows hardly any visible ripple, even with the 'scope Y GAIN control turned all the way up. A DC voltage check from Point 10 to ground shows normal voltage.

8. You have located the trouble, and all that is left to do is to completely remove the old condenser and rewire in the new one.

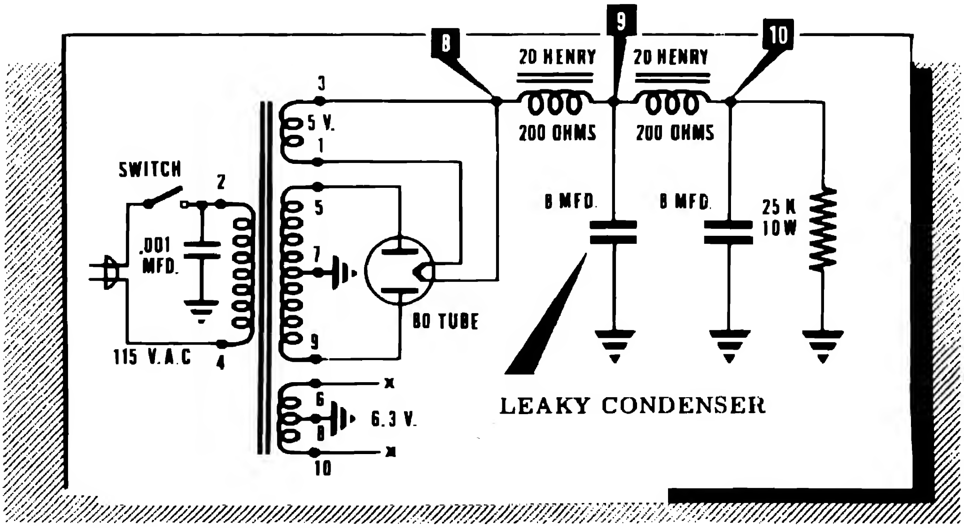
9. Here is proof that the electrolytic condenser was the cause of the trouble:

   A. There was excessive hum and low DC voltage at the output.

   B. Signal tracing indicated that the loss in filtering action occurred at the first condenser.

   C. An ohmmeter check indicated that the condenser had an internal low resistance to ground (leaky condenser).

   D. Replacing the condenser restored normal DC output voltage and very low hum.



TROUBLESHOOTING POWER SUPPLIES

Experiment—Troubleshooting a Power Supply

You have found out about troubleshooting methods on the previous sheets. Several examples have been given showing the general procedure you should follow. After going over the methods involved, you will get practice in finding troubles put into your power supply by someone else in your class. Then you will troubleshoot a few power supplies that have troubles put in by the instructor.

To prove to yourself that the general procedure is the same for locating defects in all power supplies of this type, you will then troubleshoot a power supply that you have not seen before. This power supply will be in a push-pull amplifier similar to one that you will soon build yourself.

This Is What You Will Need

1. Your completed power supply with type 80 rectifier tube
2. OS-8A/U oscilloscope
3. DC multimeter
4. Assorted test leads
5. Defective parts—tubes, condensers, chokes, etc. to be furnished by the instructor
6. An 82K or 85K resistor, 2 watts

While performing the experiment on troubleshooting power supplies, you will see most of the common troubles which occur. To prevent damage to the components certain troubles will not be used, such as shorted transformers and filter condensers. Both of these troubles cause overheating and can usually be detected visually. Make certain to observe the special precautions listed on the following sheets both to prevent damage to the circuit parts and to reduce the possibility of receiving an electric shock.

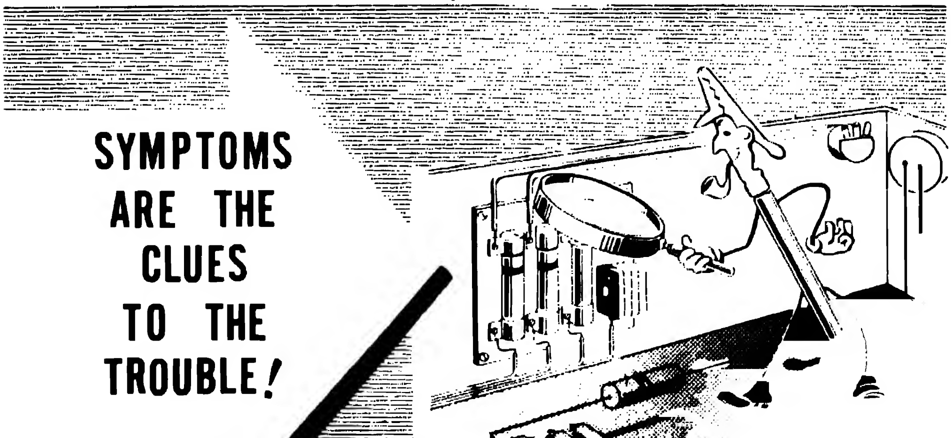
TROUBLESHOOTING POWER SUPPLIES

Experiment—Typical Power Supply Troubles

You now know the general procedure for troubleshooting. You also understand the operation of the circuit and the function of each component. Knowing this and knowing what the symptoms are for each possible trouble will make it possible for you to troubleshoot any power supply you will ever see.

TROUBLE	SYMPTOMS
1. Open filter choke	No output. Voltmeter reads higher than normal voltage before the choke and zero after the break.
2. Open filter condenser	Output signal has greatly increased ripple or hum.
3. Leaky filter condenser	DC voltage output lowered. Output signal shows increased ripple or hum.
4. Faulty rectifier tube	Wave form at rectifier heater appears as half-wave pulsating DC (one plate burned out), normal but decreased amplitude (decreased filament emission) or there is no signal at all (filament burned out).

Insert each of the troubles numbered 1 through 4 above in your power supply circuit. To simulate an open component, simply unsolder one of its connections and tape the loose wire to prevent the possibility of its shorting to ground. To simulate a leaky condenser, connect an 82K, 2-watt resistor in parallel with the condenser. Obtain a faulty rectifier from your instructor. For each trouble you insert, look for the symptoms with a voltmeter, oscilloscope and ohmmeter. Be sure you understand why you obtain the symptoms you get. Do not attempt to simulate a shorted filter condenser—the next sheet will tell you why.

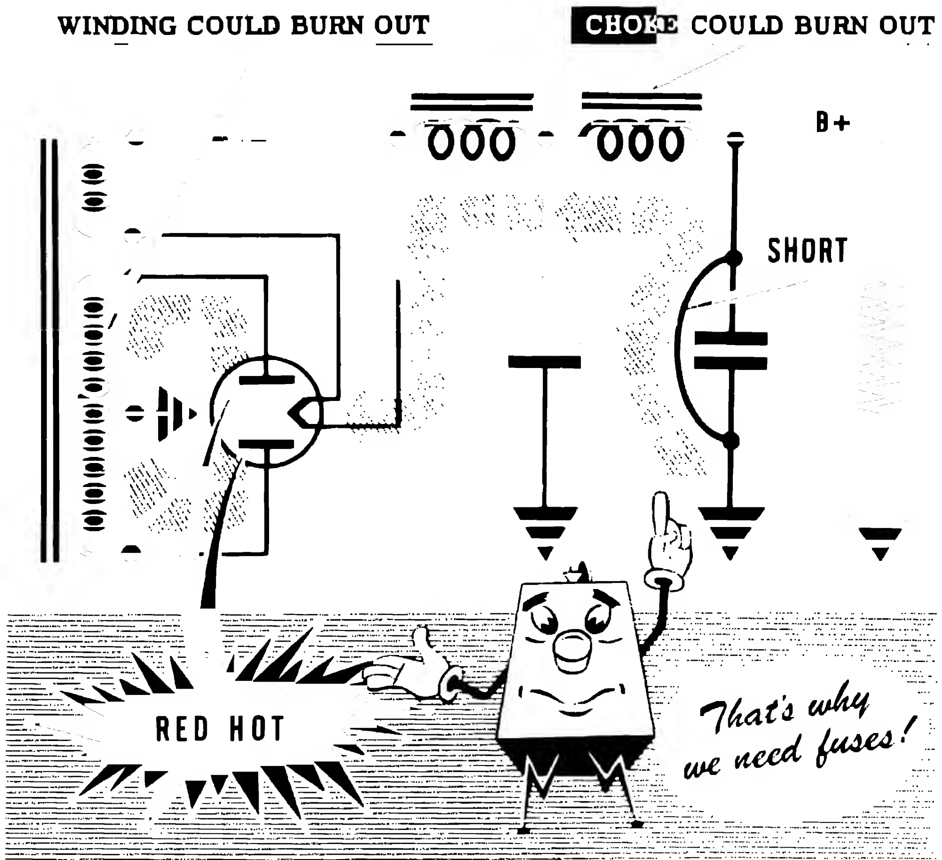


TROUBLESHOOTING POWER SUPPLIES

Experiment—A Shorted Filter Condenser

One of the most common troubles found in power supplies using electrolytic filter condensers is that the electrolytic condenser shorts internally, causing the rectifier tube to burn out. It may also cause the filter choke to burn out, and may also damage the power transformer. As a result, electrolytic filter condensers are seldom used in power supplies in Navy electronics equipment. Most of the filter condensers used are paper condensers, which seldom fail due to internal shorting. The only advantage in using electrolytics condensers is that they combine large capacities in small volume. Above 10 mfd., paper condensers usually become prohibitive in size and electrolytics must be used.

To demonstrate the effect of a shorted filter condenser on the rectifier tube, your instructor will momentarily short out B+ to ground on the power supply demonstration panel. Observe how the plates of the rectifier become red hot due to the tremendous current flow. In actual equipment, the primaries of all power supplies are fused so that, if any short does develop, the fuse will blow first, thus protecting the components of the power supply.



TROUBLESHOOTING POWER SUPPLIES

Experiment—Troubleshooting Procedure

You have seen what the method is when you have an unknown trouble. First you give the power supply a visual check for loose tubes, shorts and damaged parts. Then you plug in the power supply and check for smoking or boiling parts and tubes that are not heating up.

Whether or not you think you have found the trouble and repaired it, you should go ahead and check your work. Using a DC voltmeter across the bleeder resistor, see whether you are getting any high-voltage DC output—this tells you whether you are looking for a complete open or short or whether you are looking for a defective part. Proceed to trace the power line signal through the power supply, using your 'scope. When you come to the point where the signal disappears or varies from what it should be, that is the point at which you should look for the trouble.

Someone else in your class will put a trouble into your power supply and you will put a trouble into his. You will then find the trouble, repair it and note down what you did on the data sheet at the end of this set of instruction sheets.

After you have located a few troubles and recorded what you did, the instructor will insert some trouble in your power supply. You will locate this trouble in the same way and make a note of what you did on the data sheets.

Remember that this practice is for your special benefit and you will find it very useful later in the course and out in the Fleet. Don't hurt anyone's chances by giving any hints as to what is wrong with his power supply.

Inserting a Trouble into Someone Else's Power Supply

1. The instructor will assign you a partner. You will put a trouble into his power supply and he will put one in yours.

2. You can put any of the following defects into your partner's power supply:

   A. A loose or broken connection anywhere—just be very careful to fix it so that it will not accidentally short to ground and burn out a valuable transformer.

   B. Exchange his good rectifier tube with a faulty one. There will be several types of faulty tubes available from which to choose.

   C. Exchange his filter condenser or one of his chokes with a faulty one.

Caution!

Under no conditions insert a short to ground into someone's power supply—if there is no fuse this may only ruin a good transformer or a good tube. When inserting a trouble, avoid anything that can possibly cause a short to ground.

Experiment—Troubleshooting Procedure (continued)

CAUTION

It is best to remove the power supply line plug each time you change test points in this laboratory period. This is necessary because either one switch point or transformer terminal 4 may be "hot" even though the switch is off, since they are connected directly to the power line. When you get some experience in working with "hot" circuits, you will learn how to touch your test prod from point to point without turning off the switch. For the present, remember that you can be badly shocked if you touch high voltage and any ground at the same time, so be sure to remove the line plug while you are connecting any instrument to the power supply.

When working with circuits where high voltage points are exposed, always work with one hand only. Keep the other hand and the rest of your body away from any metal objects which might possibly be grounded. If you do touch a high voltage point, then the current will not go through your body.

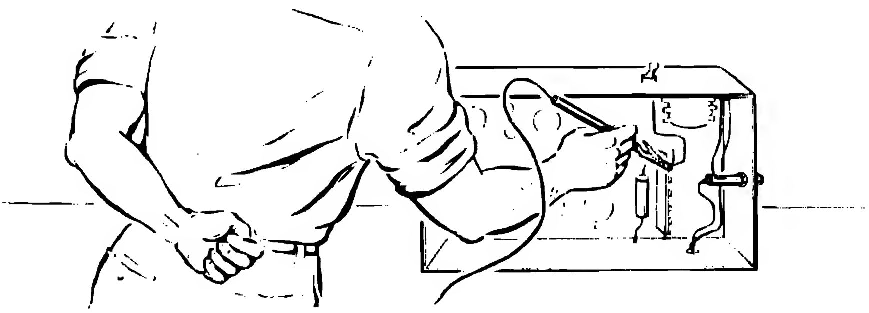
Follow a logical troubleshooting procedure and locate the trouble. Repair it. While you work, fill in the blanks on the data sheet at the end of this set of Instruction Sheets—this will help you keep a record of what you are doing.

Locating Trouble Put In by the Instructor

The instructor will insert a trouble in your power supply which you should locate and correct. The purpose of this troubleshooting is to give you a chance to work on troubles that are more skillfully hidden than those that your partner could put in. Also there may be troubles such as shorts, defective transformers, etc. that you have not yet had a chance to work on. The instructor will watch your technique in locating the trouble and he will give you some pointers on improving your methods.

1. The instructor will tell you which power supply to troubleshoot.

2. Use a logical troubleshooting procedure and keep a record of what you find on the data sheet at the end of this set of instruction sheets.

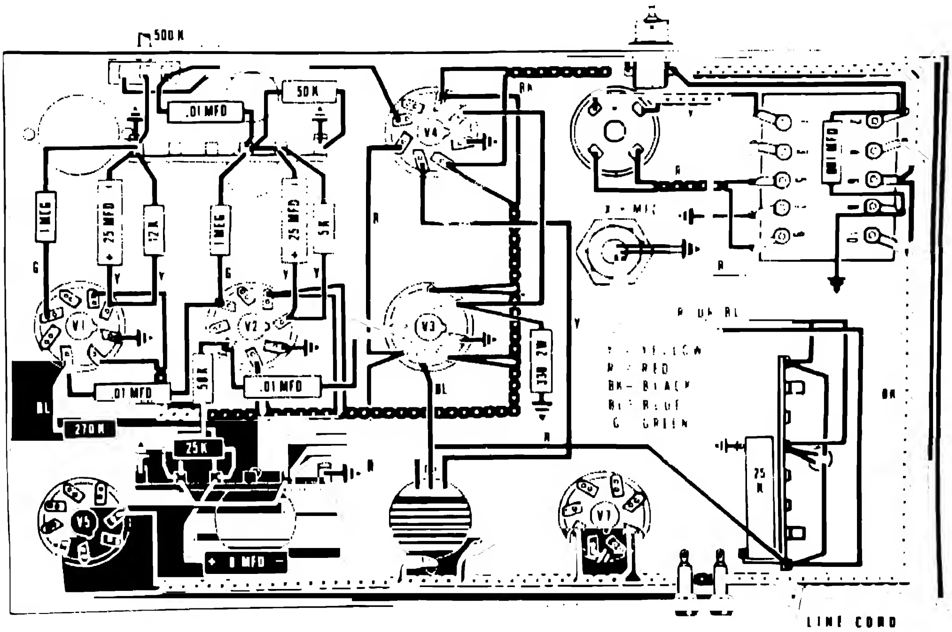


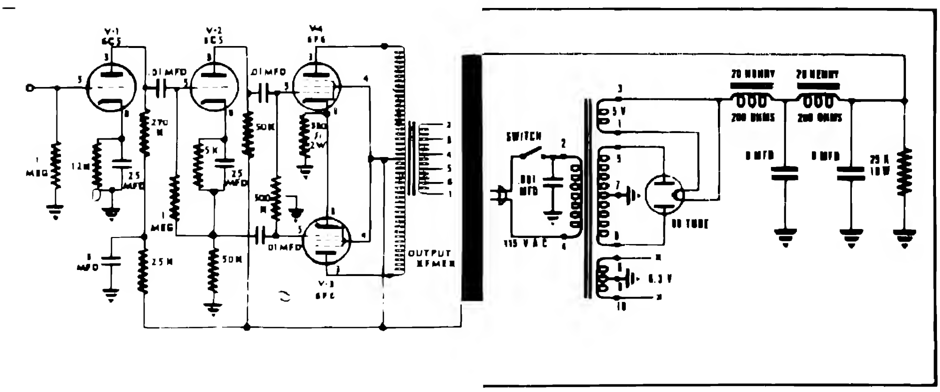
Experiment—Troubleshooting Procedure (continued)

The instructor will ask you to troubleshoot the power supply in a push-pull amplifier similar to one that you will soon build yourself. The reason that it is used is to demonstrate to you that by using the outlined method of troubleshooting you can readily find the trouble in any power supply without any further directions.

The only information you need to know is that it is similar to your power supply. You will find the schematic and the pictorial diagrams on this sheet. Locate the power supply portion of the circuit and find the trouble without any further instructions.

Record what you find on the data sheet and give reasons to prove that you have found the trouble. Do not make any repairs.





TROUBLESHOOTING POWER SUPPLIES

Experiment—Data Sheet

Trouble No. 1

Visual Check — The following troubles were found in the visual check:

1. ______________________________
2. ______________________________
3. ______________________________

Signal Tracing

1. The output voltage was ____ volts DC.
2. The first point at which a defective signal was found was Point ____.
3. The defect in the signal was as follows:

   ____

4. The part found to be defective was ______________
5. The following reasons prove that the part was defective:

   a. ______________________________

   b. ______________________________

   c. ______________________________

Trouble No. 2

Visual Check — The following troubles were found in the visual check:

1. ______________________________
2. ______________________________
3. ______________________________

TROUBLESHOOTING POWER SUPPLIES

Experiment—Data Sheet (continued)

Signal Tracing

1. The output voltage was____volts DC.
2. The first point at which a defective signal was found was Point ____.
3. The defect in the signal was as follows:

   ____

4. The part found to be defective was ____________________
5. The following reasons prove that the part was defective:

   a. ____

   b. ____

   c. ____

   d. ____

Trouble No. 3

Visual Check — The following troubles were found in the visual check:

1. ____
2. ____
3. ____

Signal Tracing

1. The output voltage was___ volts DC.
2. The first point at which a defective signal was found was Point ____.
3. The defect in the signal was as follows:

   ____

4. The part found to be defective was ____________________
5. The following reasons prove that the part was defective:

   a. ____

   b. ____

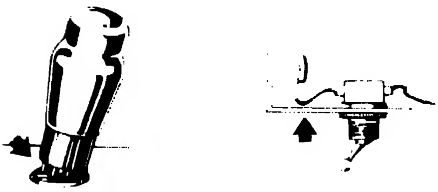
   c. ____

   d. ____

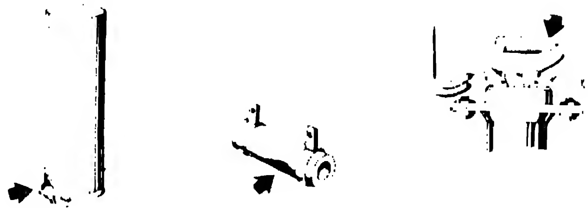
TROUBLESHOOTING POWER SUPPLIES

Review of Troubleshooting

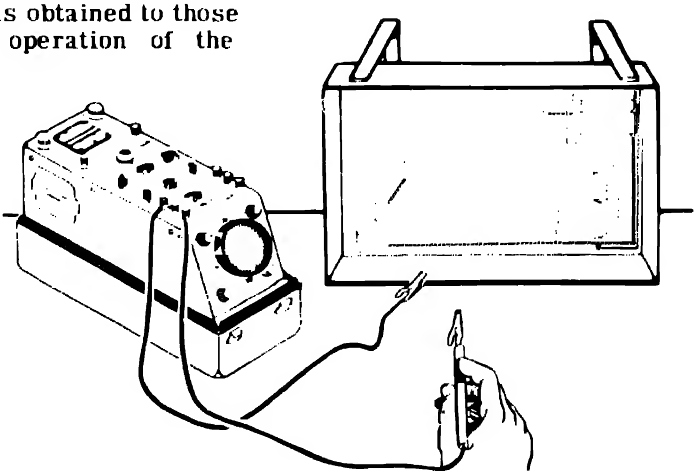
To review troubleshooting consider the procedure outlined below:



VISUAL CHECK —A check made both before and after applying power to the circuit. With no power applied check for loose tubes, shorts, discolored or leaking transformer, loose or broken connections, charred resistors and leaking condensers. With power applied check for smoking parts, cold tubes and sparking.



SIGNAL TRACING — Trace the AC input signal through the circuit using an oscilloscope to observe the wave forms at various points in the circuit. Compare the wave forms obtained to those indicating normal operation of the same circuit.



VOLTAGE REGULATOR CIRCUITS

The Need for a Voltage Regulated Power Supply

The DC output voltage ("B+") of a power supply is affected by variations in the power line voltage and by changes in the load current drawn from the supply.

In a conventional power supply, such as the full-wave or half wave power supply, the B+ voltage output rises when the AC line voltage rises and the B+ voltage falls when the AC line voltage falls. In addition to this effect, the B+ voltage gets lower and lower as more and more current is drawn from the B+ terminal. This effect of a changing B+ voltage is seldom troublesome because many electronic circuits draw a fairly constant current out of the B+ power supply, and because they are not very sensitive to the usual changes in the AC line voltage. However, there are some circuits which are very sensitive to voltage changes. A comparatively small rise and fall in the B+ voltage will cause inaccurate operation. Unfortunately, some of these very sensitive circuits are used to keep radar receivers in tune and to mark the range of enemy ships and planes on the radar screen— in these cases a rise or fall in B+ voltage may be serious.

These sensitive electronic circuits contain voltage regulated power supplies which put out a constant B+ in spite of line voltage changes and in spite of changes in the B+ current drain.

The voltage regulation of a power supply can be improved by changes in the power supply design or by the addition of voltage regulator circuits.

VOLTAGE REGULATOR CIRCUITS

Voltage Regulation

By this time you have done numerous experiments on general purpose power supplies. You understand the theory of operation of rectifier circuits and filter circuits. You appreciate the importance of maintaining the power supply in good working order so that the complete electronic equipment may be able to do its job.

Now you are going to study voltage regulated power supply circuits which are required to do specialized jobs that the ordinary general purpose power supply cannot do. Like other circuits you will use, voltage regulator circuits range from very simple circuits using only one or two parts to very complex circuits requiring many components. However, all of these circuits operate in the same way as the basic regulator circuits.

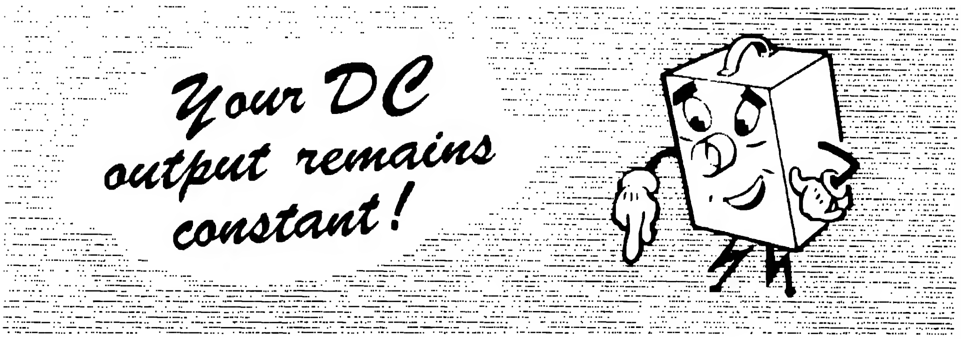
You are going to learn all about these circuits by:

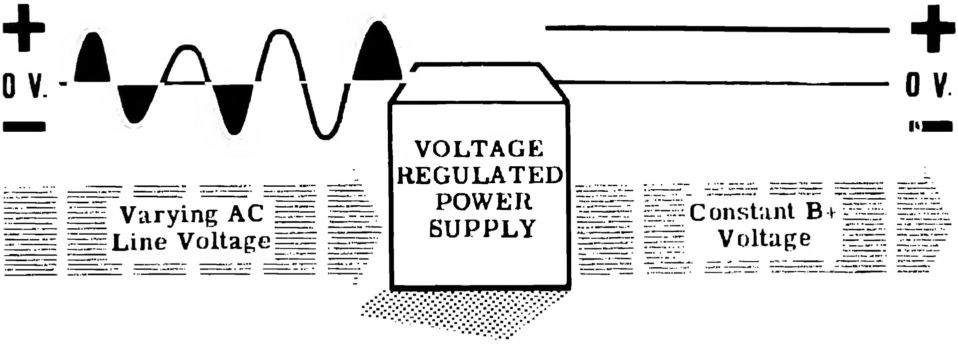
1. Reading about the operation of the circuits and the need for them.

2. Building a simple voltage regulator circuit.

3. Testing this circuit under varying load and line voltage conditions.

4. Troubleshooting the voltage regulator circuit.



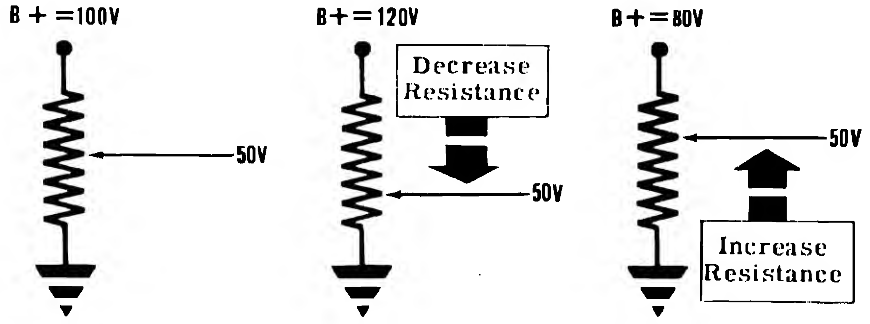


Voltage Regulation (continued)

You already know the two most important factors which affect the B+ voltage output in a conventional power supply. When the AC line voltage goes up, the B+ output voltage goes up; and, when the AC line voltage goes down, the B+ output voltage goes down. Also, when there is a small current drain out of the B+ terminal, the B+ voltage is higher than when there is a large current drain. What you want to know now is how the voltage regulator circuit overcomes both these problems.

If you connect a potentiometer across B+ and ground in any conventional power supply, you have a perfect hand-operated voltage regulator.

Assume that you have a 1000-ohm potentiometer and a power supply with a B+ of 100 volts. Also assume that you want a steady output voltage of 50 volts. You first adjust your potentiometer so that the center tap is right at the middle of the potentiometer resistance. If the B+ voltage rises momentarily due to an increase in AC line voltage or a decrease in B+ current drain, all you do is move the tap closer to ground (decrease the resistance between tap and ground) until you get 50 volts again. If the B+ voltage falls due to a decrease in the AC line voltage or an increase in B+ current drain, all you do is move the tap away from ground (increase the resistance between tap and ground) until you get 50 volts again.



You can see that the hand-operated voltage regulator works very well. You increase or decrease the resistance between ground and the output voltage tap to increase or decrease the output voltage back to the desired value whenever the B+ supply voltage falls or rises for any reason.

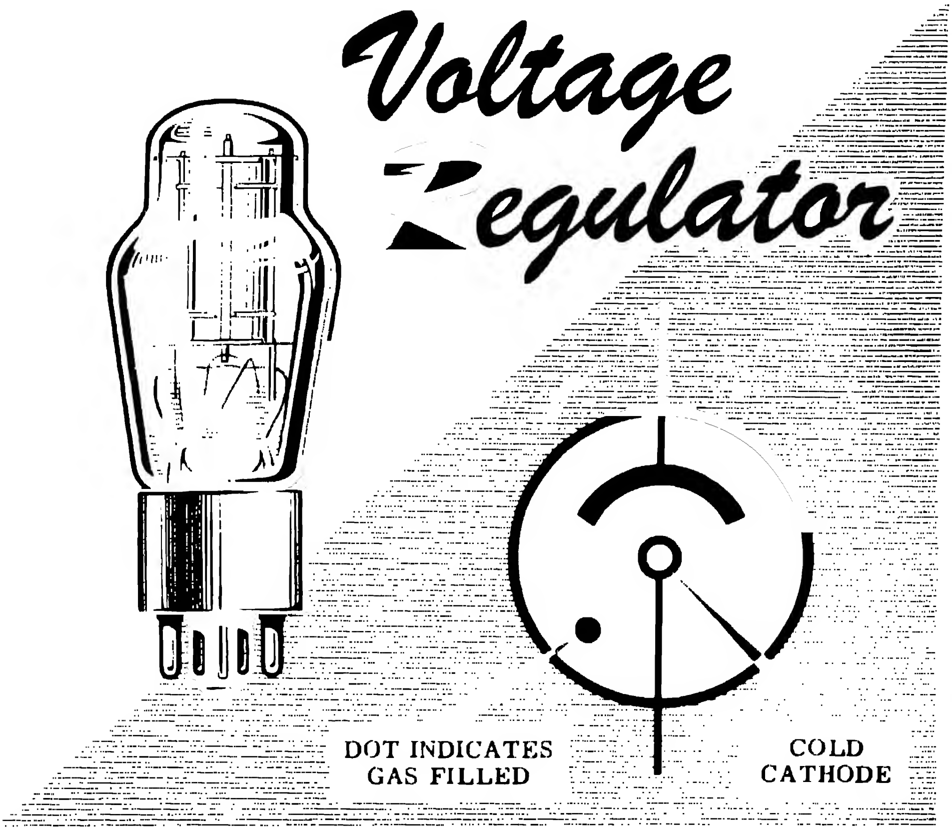
The main fault with this method is that it is too slow. First, the output voltage must change. Then you must notice that it has changed, and then you must increase or decrease the resistance between the voltage tap and ground to get back the desired voltage output. When you consider that there are many electronic circuits in a radar system which must have a steady voltage, you can see that many men would be needed to keep them all regulated.

The voltage regulator circuit solves all your problems! The voltage regulator tube automatically increases or decreases its internal resistance as the B+ supply voltage falls and rises, so as to maintain a constant voltage across itself.

VOLTAGE REGULATOR CIRCUITS

The Voltage Regulator Tube

The voltage regulator tube consists of a plate and a cathode placed in an envelope containing a gas at low pressure. There is no filament and, therefore, the tube is known as a cold cathode type tube. The radio symbol for the tube is as illustrated. The dot inside the envelope indicates the presence of a gas.



When a large enough potential is applied between the cathode and the plate, the gas in the tube conducts and electrons flow from cathode to plate. Conduction is characterized by a bluish glow inside the tube—the heavier the conduction the brighter the glow.

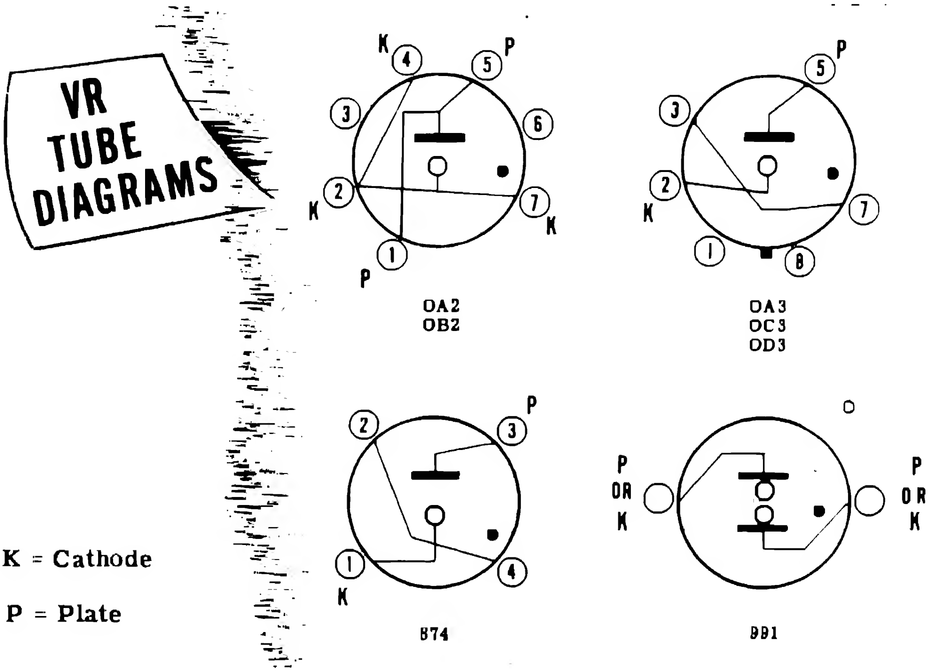
The numbering system used for voltage regulator tubes has been changed in recent years. The VR-150/30, the VR-90/30 and the VR-75/30 are old numbers no longer used. The term "VR" meant voltage regulator; the first number, "150" etc., stood for the operating voltage of the tube—the voltage at which it regulated. The last number represented the maximum rated current that could pass through the tube without damaging it. In all regulator tubes there is also a minimum operating current of about 5 ma. The tube will stop conducting if the current through it drops below this value. A wide range of regulated voltages can be had by using any of the voltage regulator tubes singly or in series combinations.

VOLTAGE REGULATOR CIRCUITS

The Voltage Regulator Tube (continued)

The new numbering system for VR tubes is as follows:

Tube Type	DC Operating Voltage	Current Range Ma.
OA2	151	5 to 30
OA3	75	5 to 40
OB2	108	5 to 30
OC3	108	5 to 40
OD3	153	5 to 40
874	90	10 to 50
991	59	0.4 to 2.0



Under this new system there are available a larger variety of DC operating voltages and current ranges.

The VR tube is a diode which consists of a thin vertical rod held in position inside of a thin metal cylinder. The air is removed from the tube envelope and is replaced by a small quantity of neon or helium gas mixed with a small quantity of argon gas. As long as the current flow through the tube is kept within the listed limits the plate voltage of the tube will change very little.

If operating voltages higher than those listed above are required, two or more VR tubes may be connected in series. In this case the operating voltage will become the sum of all the operating voltages of the tubes connected in series. Parallel operation is used when a larger current is required.

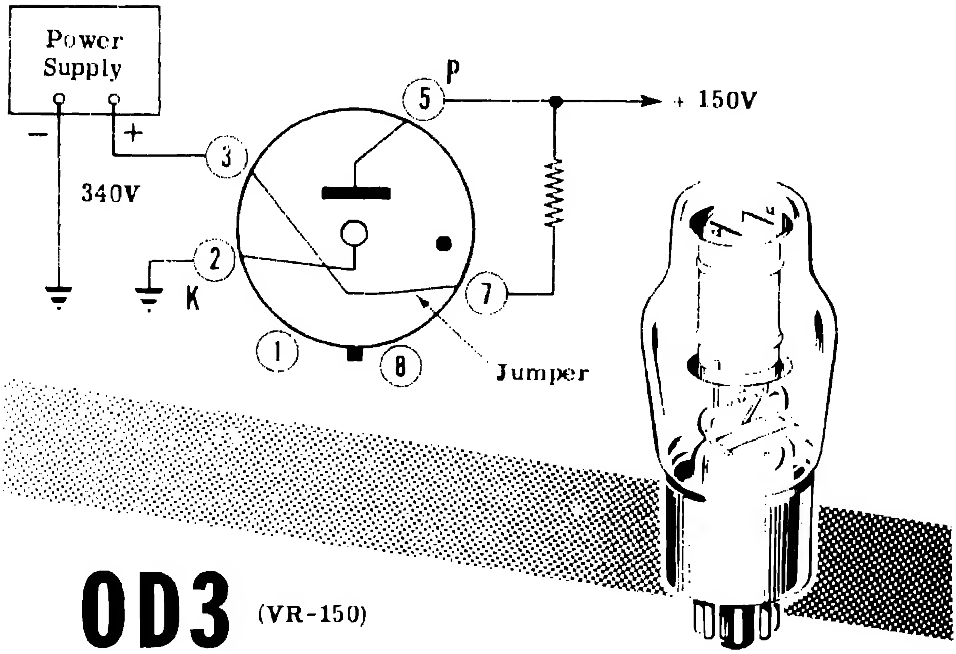
VOLTAGE REGULATOR CIRCUITS

A Simple VR Tube Circuit

Here is an example of how a VR tube is used in a typical circuit. Suppose that you have a power supply with an output voltage of 340 volts DC. You need to supply voltage to a special circuit that needs 150 volts DC with a current variation of from 10 to 30 milliamps. This circuit requires that the 150 volts DC be kept constant in spite of the current change.

Since you want a constant voltage of 150 volts DC with a maximum current drain of 30 milliamps, an OD3 (VR-150) will meet your requirements. Here are the operating characteristics of the OD3 (VR-150) as listed by the manufacturer - note that they meet your requirements:

DC power supply voltage . . . . . . 185 volts min.
DC starting voltage . . . . 160 volts
DC operating voltage . . . . . . 153 volts
DC operating current . . . . 5 to 40 ma.
For a current variation of from 5 to 30 ma. the voltage will change 2 volts.
For a current variation of from 5 to 40 ma. the voltage will change 4 volts.



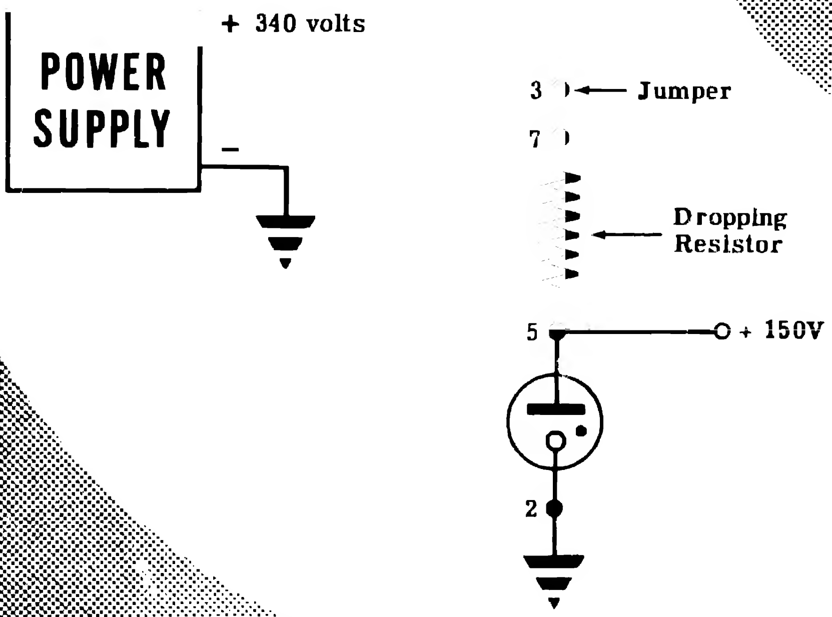
OD3 (VR-150)

Notice that there is a "jumper connection" between pins 3 and 7 inside the tube. If pins 3 and 7 are wired in series with the circuit, this jumper will act as a switch. When the VR tube is pulled out, the circuit requiring the 150 volts will be disconnected from the power supply. If this jumper were not connected as a switch and the VR tube were pulled out, the 150 volt circuit would receive more than 150 volts—resulting in damage to its components or in improper operation.

VOLTAGE REGULATOR CIRCUITS

A Simple VR Tube Circuit (continued)

In order to illustrate the circuit described on the previous sheet, the VR tube is connected to the power supply like this:



Note that the 150 volt point is disconnected from the power supply if the VR tube is pulled out.

In order to determine the size of the dropping resistor, you must begin with a condition when no load is connected to the 150 volt output terminal. You must then adjust the size of the dropping resistor so that the maximum current (40 ma.) will flow through the VR tube. You already know that the output of the power supply is 340 volts, so the voltage across the resistor will have to be 340 - 150 or 190 volts. For these current and voltage conditions the size of the resistor is calculated from Ohm's law:

$$R = \frac{E}{I} = \frac{190V}{0.04A} = 4750 \text{ ohms}$$

The wattage of the resistor is found from the power formula

$$W = EI = 190V \times 0.04A = 7.6 \text{ watts.}$$

The resistance you want according to the above results is a resistor of 4750 ohms rated at 7.6 watts. Such a resistor is not available except on special order. The nearest standard value of wire wound resistance available is 5000 ohms. This resistor would allow 38 ma. to flow through the tube, which is suitable for your purposes. A 10 watt resistor could be used but a 25 watt resistor would probably be best since the size and cost are not much more and the danger of burnouts would be reduced.

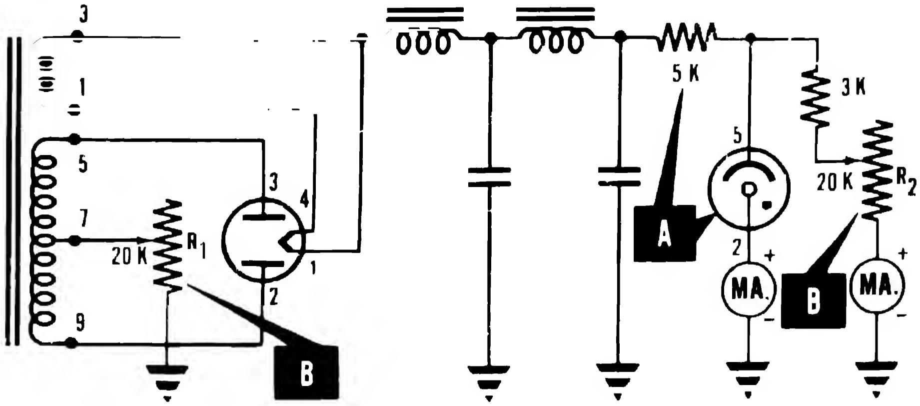
VOLTAGE REGULATOR CIRCUITS

Experiment—Building a Voltage Regulator Circuit

You are going to modify your full-wave rectifier power supply, which is mounted in the chassis, to a voltage regulated power supply as illustrated.

A. You are going to add a resistor and a voltage regulator tube (OD3) to make up the voltage regulator circuit.

B. You are going to add two variable resistors whose function will be to simulate the effect of a varying load and a varying line voltage. You will observe how the voltage regulator circuit keeps the output voltage constant under varying-load current and line voltage conditions.



This Is What You Will Need

1. One chassis with mounted full-wave rectifier choke input filter power supply
2. One voltage regulator tube OD3
3. Two 20K potentiometers (5W)
4. A 5K resistor (10W)
5. A 3K resistor (5W)

VOLTAGE REGULATOR CIRCUITS

Experiment—Building a Voltage Regulator Circuit (continued)

1. Mount the two potentiometers on the chassis as illustrated.

Note that the potentiometers are used as rheostats.

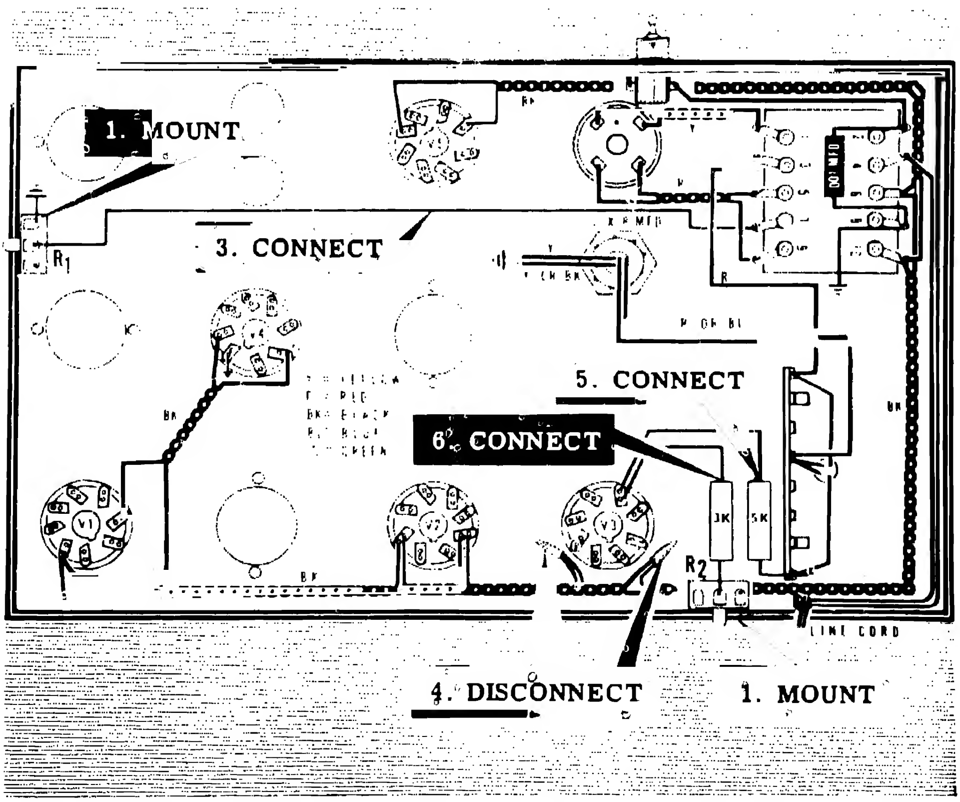
2. Remove the ground connection from terminal 7 of the transformer.

3. Connect a wire from terminal 7 of the transformer to the center lug of the rheostat (R_1) as illustrated. Ground one end of the potentiometer (R_1).

4. Remove the filament wires from the voltage regulator tube socket. Tape up the open ends and push them to the side.

5. Remove the 25K bleeder resistor and connect the 5K (10W) resistor between the B+ terminal lug and pin 5 of the voltage regulator tube socket.

6. Also to pin 5 connect the 3K (5W) resistor, the other end of which goes to the center lug of the rheostat (R_2).



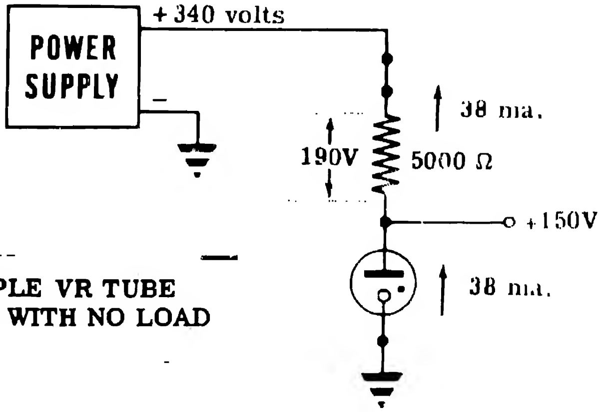
Your wiring is now complete. Clean out the chassis of all bits of solder and loose wires. Check your wiring against the schematic and pictorial to make sure that your wiring is correct.

VOLTAGE REGULATOR CIRCUITS

Voltage Regulation When Load Current Varies

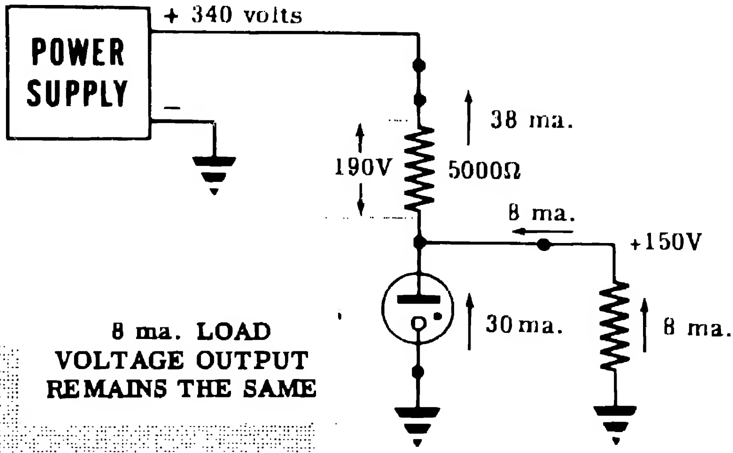
Now that you have the details of a VR tube circuit worked out, suppose you find out how it operates to keep the output voltage stable at 150 volts in spite of a change in output current. In order to do this, the VR tube increases and decreases its resistance to adjust to changes in load and supply voltage.

When no load is attached to the 150 volt output, 38 ma. will flow through the tube. Since the current flowing through the tube is within the rated value, the VR tube adjusts its internal resistance so that the voltage at the plate is 150 volts.



A SIMPLE VR TUBE CIRCUIT WITH NO LOAD

Suppose you attach an 8 ma. load to the 150 volt terminal. Of the 38 ma. flowing through the dropping resistor, 8 ma. flows through the load and 30 ma. flows through the VR tube. Since the VR tube current is yet within the rated range of 5 to 40 ma., the VR tube adjusts its internal resistance so that the plate voltage remains at 150 volts.

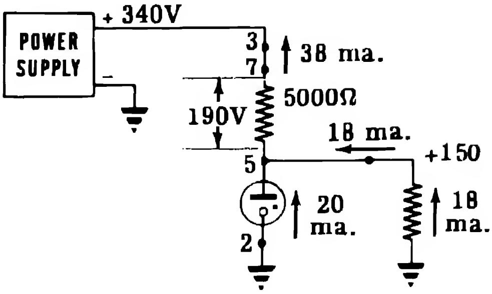


8 ma. LOAD
VOLTAGE OUTPUT
REMAINS THE SAME

VOLTAGE REGULATOR CIRCUITS

Voltage Regulation When Load Current Varies (continued)

If you now increase the load on the 150 volt terminal to 18 ma., 20 ma. will flow through the VR tube, and the output voltage will remain at 150 volts. As long as the current flowing through the VR tube is within the range of 5 to 40 ma., the tube is able to adjust its internal resistance so as to keep the plate voltage essentially at 150 volts.



You may increase the load on the 150 volt output terminal until the current through the load reaches 33 ma. At this load only 5 ma. will flow through the VR tube—this is the minimum current that may flow through the VR tube and still keep the output terminal at 150 volts. Any further increase in load current will cause less than 5 ma. to flow through the tube and it will "go out" or cease glowing. From this point on the VR tube will have no effect on the output voltage, and the output voltage will be determined only by Ohm's Law.

For a load of 38 ma. on the output terminal the voltage drop across the dropping resistor will be:

$$E = IR = .038 \times 5000 = 190 \text{ volts}$$

Subtracting the voltage drop across the resistor from the voltage of the power supply gives you the following voltage at the plate of the tube:

$$340 - 190 \text{ volts} = 150 \text{ volts}$$

For a load of 40 ma. on the output terminal the voltage drop across the dropping resistor will be:

$$E = IR = .040 \times 5000 = 200 \text{ volts}$$

And the voltage at the plate of the tube will be:

$$340 \text{ volts} - 200 \text{ volts} = 140$$

Similarly the following loads on the output terminal will result in the following voltages at the output terminal.

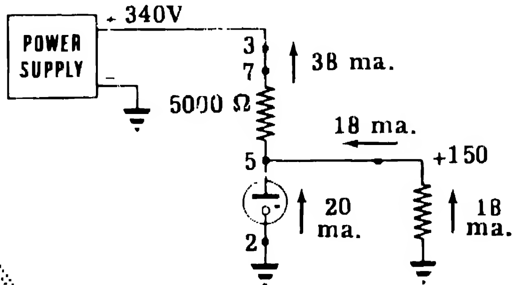
Load Current	42 ma.	44 ma.	46 ma.	48 ma.
Output Voltage	130V.	120V.	110V.	100V.

You see, therefore, that as long as the voltage regulator tube conducts its rated current the voltage remains constant. The voltage remains essentially at 150V in spite of a change in load of from 0 to 33 ma. Once the current through the VR tube becomes less than the minimum required, the tube goes out of action and Ohm's law determines the output voltage. Once Ohm's law determines the output voltage, a change in load of only 2 ma. will cause a voltage change of 10V at the output terminal.

VOLTAGE REGULATOR CIRCUITS

Voltage Regulation When Power Supply Voltage Varies

There is another aspect of voltage regulator circuits that has not been considered so far—how the voltage regulator circuit maintains a constant voltage output when the power supply voltage changes. The power supply B+ voltage will rise when the line voltage rises, and it will fall when the line voltage falls. In addition there usually are other circuits connected to the power supply B+ output voltage, in addition to the voltage regulation circuit. When these other circuits draw more current from B+, the voltage drops; and when these other circuits draw less current from B+, the voltage rises. The voltage regulator circuit must put out a constant voltage output at the plate of the VR tube in spite of these changes in B+ voltage.



Under the operating conditions shown, 38 ma. flow through the dropping resistor, 20 ma. flow through the VR tube, and 18 ma. flow through the load. If the B+ voltage were to rise to +360 volts, the VR tube would have to adjust its internal resistance so that its plate voltage remained at 150 volts. Let's see if the VR tube is able to make this adjustment.

Under these conditions the top of the dropping resistor would be at +360 volts and the bottom would be at +150 volts. This means that there will be 210 volts across the resistor and the current flow through that resistor will be determined by Ohm's law as follows

$$I = \frac{E}{R} = \frac{210}{5000} = .042 \text{ amps} = 42 \text{ ma.}$$

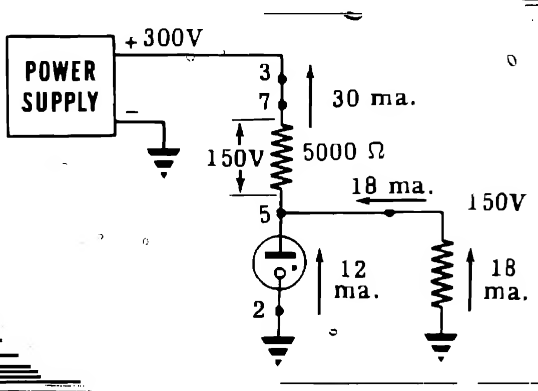
Since the load draws 18 ma. at 150 volts, the remainder of the current (42 ma. - 18 ma. = 24 ma.) must flow through the VR tube. The VR tube is designed to do its job of regulating if the current flow through it remains between 5 and 40 ma. The VR tube can adjust for this B+ voltage change and still maintain the voltage at its plate at 150 volts.

In order for the circuit to fail in its job, the B+ voltage would have to go up to over 440 volts. At this point there would be 290 volts across the dropping resistor and 58 ma. total current through this resistor. The load current would be 18 ma. and the VR tube current would be 40 ma. Any further increase in B+ voltage would cause over 40 ma. to flow through the VR tube and it would be damaged by the excessive current.

VOLTAGE REGULATOR CIRCUITS

Voltage Regulation When Power Supply Voltage Varies (continued)

Now that you have examined what happens when there is a rise in the B+ voltage supplied to the voltage regulator circuit, suppose you find out what happens when this B+ voltage falls.



If the B+ voltage were to fall to 300 volts, the VR tube would have to adjust its internal resistance so that the plate voltage remains at 150V. Let's see if the tube can make this adjustment. The voltage across the dropping resistor is 300 volts - 150 volts = 150 volts. The current through the dropping resistor is:

$$I = \frac{E}{R} = \frac{150}{5000} = .030 \text{ amps} = 30 \text{ ma.}$$

The load draws 18 ma. and the remainder of the current (30 ma. - 18 ma. = 12 ma.) flows through the VR tube. The VR tube will do its job as long as the current flow through it remains between 5 and 40 ma. The VR tube can adjust for the drop in B+ voltage and still maintain 150 volts at its plate.

In order for the circuit to fail in its job the B+ voltage would have to drop below 265. At this point there will be 115 volts across the dropping resistor and 23 ma. total current through this resistor. The load current would be 18 ma. and the VR tube current would be 5 ma. Any further drop in B+ voltage will cause less than 5 ma. to flow through the VR tube, and it will stop functioning. The voltage at the plate will then be determined only by Ohm's law as applied to the B+ voltage and the resistance of the dropping resistor.

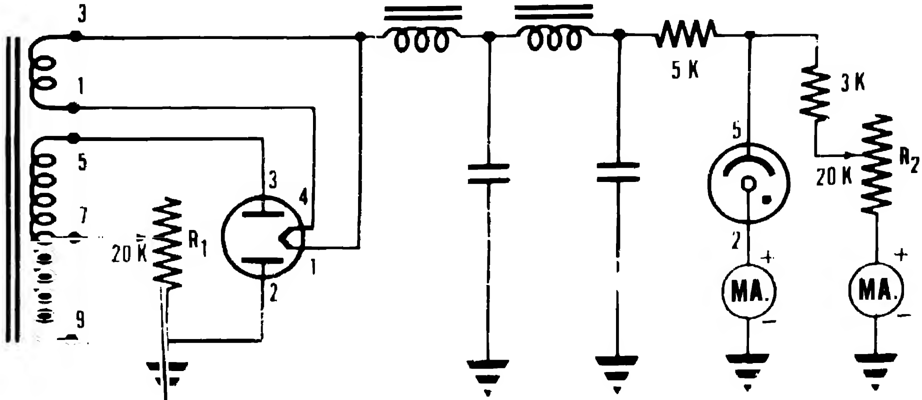
You have examined the principles behind the operation of the voltage regulator circuit. You have seen that the voltage on the VR tube plate will remain essentially constant as long as the current limitations of this tube are not exceeded. By using a voltage regulator circuit of this type you can get a constant voltage output in spite of fairly large changes in power supply voltage and in spite of sizeable changes in current drain from the regulated source.

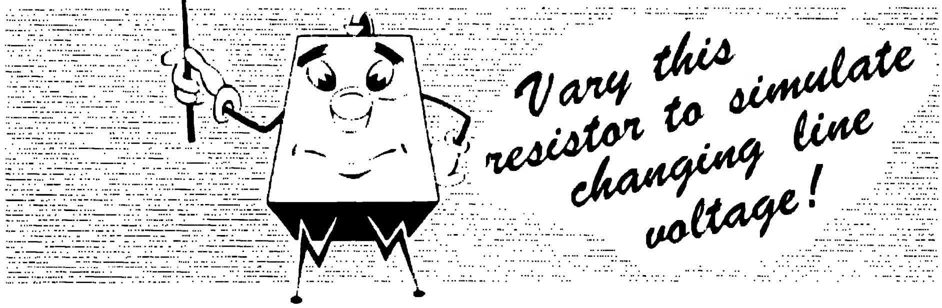
The voltage regulator circuit you have built has provisions for varying both the power supply DC voltage, and the load on the voltage regulator circuit. You will have the opportunity to see how well your voltage regulator can maintain a constant voltage under these varying conditions.

VOLTAGE REGULATOR CIRCUITS

Demonstration—The Operation of a VR Circuit

You recall that a varying line voltage causes the total output voltage of the power supply to vary, You cannot vary the line voltage easily. You can, however, simulate the effect of a varying line voltage with the variable resistor which you have placed in series with the center tap of the transformer to ground. By varying this resistor, you can increase or decrease the total output voltage of the rectifier.





This Is What Is Needed

1. One chassis with power supply and VR circuit wired as shown on sheet 11.
2. Two milliammeters, 0-50 ma.
3. One volt-ohmmeter

Note: This equipment is also needed in the experiment which follows.

VOLTAGE REGULATOR CIRCUITS

Demonstration—The Operation of a VR Circuit (continued)

The instructor will demonstrate the operation of a VR circuit first when the B+ voltage is varied and then under conditions of a changing load.

The first demonstration will show what happens when the load current is set to 10 ma. and the B+ voltage is varied from 320 volts down to 100 volts. The instructor will begin the demonstration by connecting a voltmeter to the plate of the VR tube and by inserting milliammeters in series with the VR tube and the load as shown in the illustration. The load rheostat (R_2) will be set so that the load current is 10 ma. at the same time that the transformer center tap resistor is set to 320 volts. Note that these variable resistors are potentiometers connected as rheostats. Leaving the load rheostat set at the 10 ma. load current position, the line rheostat (R_1) will be adjusted so that the B+ voltage is lowered to 100 volts in steps of 10 volts. The results will be entered in a table under the headings shown in the illustration. This demonstration will prove that the voltage across the voltage regulated load resistor will remain essentially constant over a wide range of B+ voltage variation. The VR tube will do the job of regulating the voltage at its plate as long as the current through the tube remains between 5 ma. and 40 ma.

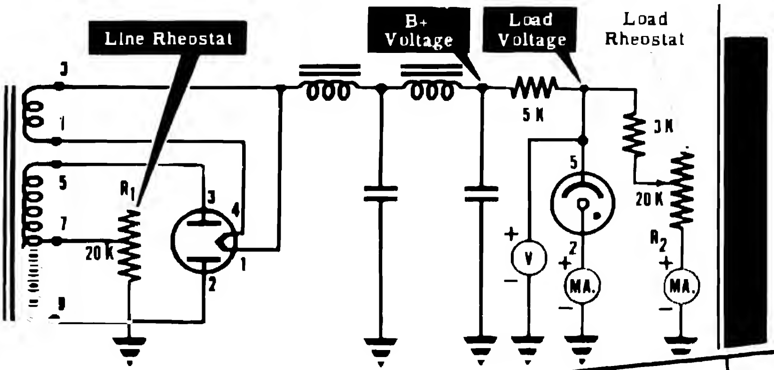


Table of Results			
B+ Voltage	VR Tube Current	Load Current	Load Voltage
320			

The second demonstration will show what happens when the B+ voltage is held constant and different load currents are drawn from the regulated voltage appearing at the VR tube plate. At the beginning of the demonstration the transformer line rheostat will be adjusted so that the B+ voltage is at a maximum, and the load rheostat will be set so that minimum current flows. Leaving the B+ voltage set at its maximum, the load current will be increased to 40 ma. in steps of 5 ma., and the results will be entered in a table identical to that used in the first demonstration. This demonstration will prove that the voltage at the VR tube plate will remain essentially constant over a wide range of load current changes. The VR tube will do its job as long as the current through the tube remains between 5 ma. and 40 ma.

VOLTAGE REGULATOR CIRCUITS

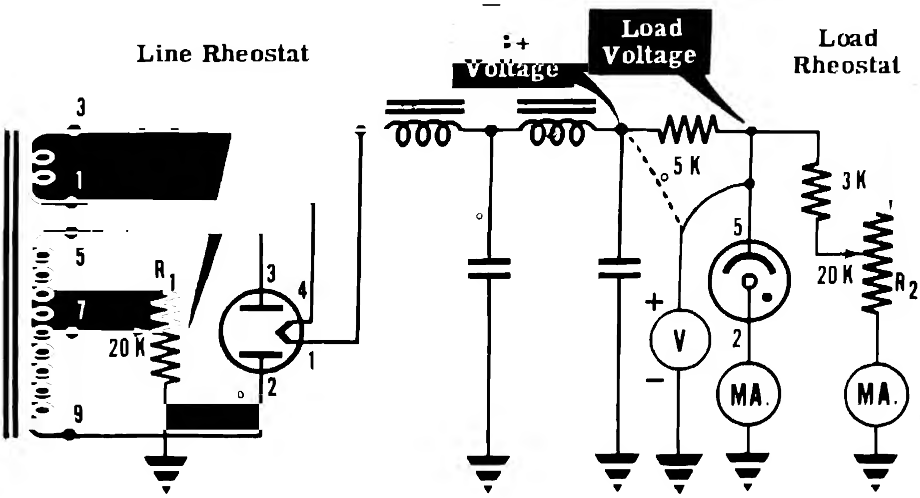
Experiment—VR Circuit Operation With Varying B+ Voltage

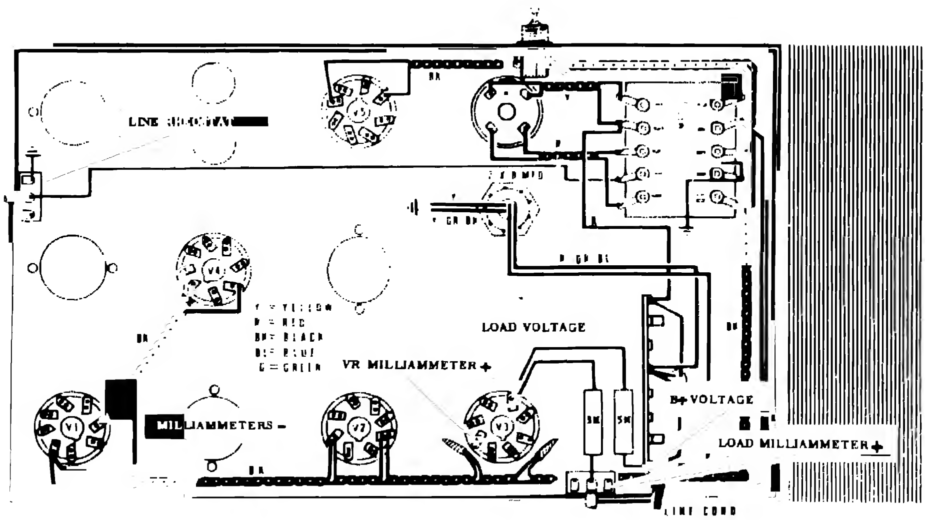
1. Connect the positive lead of one milliammeter to the load potentiometer as illustrated. Connect the negative lead to ground. The milliammeter is now in series with the load and can measure the load current.

2. Connect the positive lead of the other milliammeter to pin 2 of the VR tube. Connect the negative lead to ground. This milliammeter is now in series with the VR tube and will measure tube current.

3. Have your voltmeter ready to take readings.

4. Make up a table similar to the one on the following sheet so that you can record your readings.





VOLTAGE REGULATOR CIRCUITS

Experiment—VR Circuit Operation With Varying B+ Voltage (continued)

5. Turn the line rheostat to its minimum resistance position by turning its shaft completely clockwise.

6. Before you apply power to the circuit, check the resistance from pin 5 of the voltage regulator tube to ground. You should read at least 3,000 ohms. If you read zero, you have a short across the output. Be sure to locate the cause of the short and remove it before you apply power to the circuit. When your resistance reading is normal, have your instructor issue you an 80 tube and a OD3. You can now proceed with the experiment.

7. Apply power to the circuit. Notice that the VR tube starts to glow, indicating that it is conducting current.

8. Adjust the load rheostat for a load current of 10 ma.

9. With your voltmeter on the 500-volt range, measure and record the B+ voltage and the regulated load voltage. Also record the load current and the VR tube current.

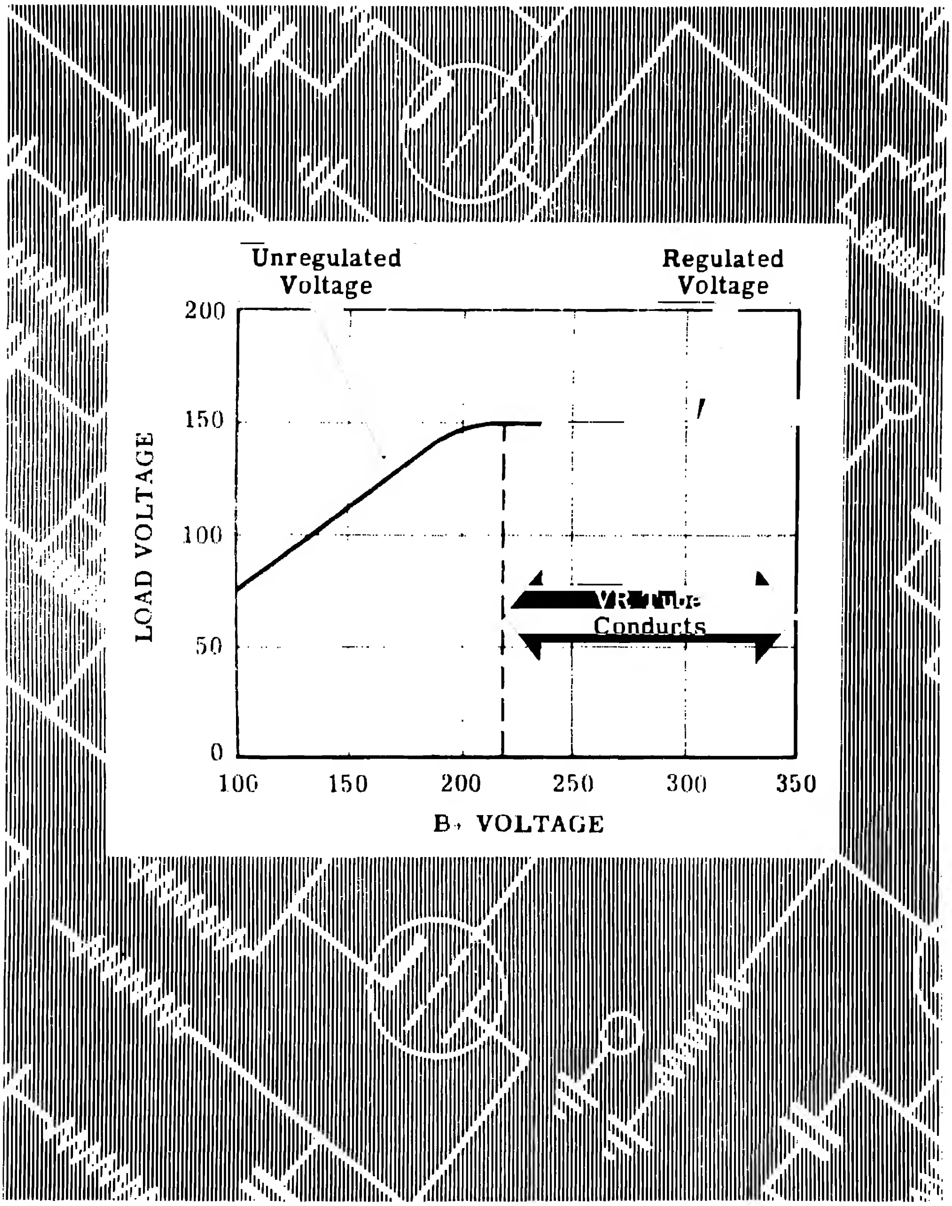
10. Decrease the B+ voltage in 20-volt steps by varying the line rheostat. Record all the necessary data at each step.

Table of Results

B+ Voltage	VR Tube Current	Load Current	Load Voltage
320			
300			
280			
260			
240			
220			
200			
180			
160			
140			
120			
100			

Experiment—VR Circuit Operation With Varying B+ Voltage (continued)

You now have recorded, on the Table of Results, the data which should tell you how constant the voltage regulator keeps the output voltage under varying line voltage conditions. The illustration below shows a graph of a typical set of data. On this graph, you can see that for a wide range of B+ voltages, the load voltage remains constant at 150 volts. You can also see that it is over this range of B+ values that the VR tube conducts.



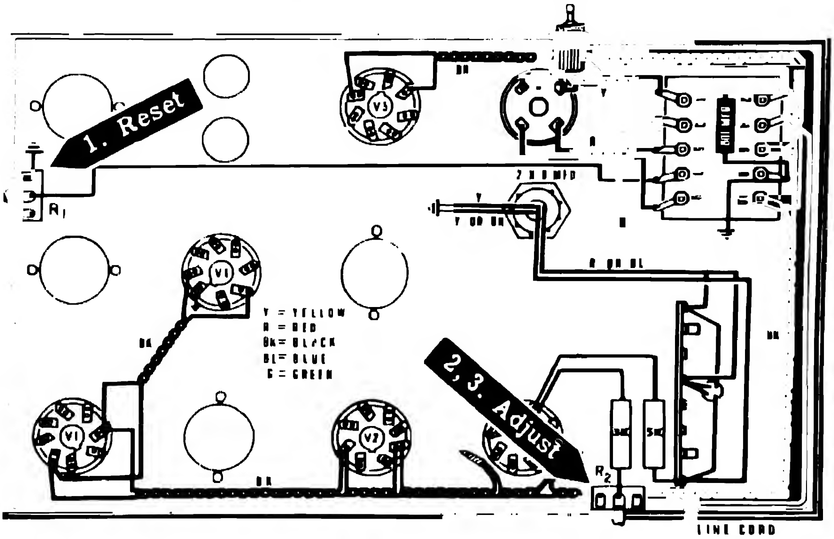
Experiment—VR Circuit Operation With Varying Load Current

The effect of a varying load can be obtained by varying the rheostat R_2 in the load circuit. You will make up a chart exactly as you did before and record data on it. Have your voltmeter ready to take voltage readings.

1. Turn the line rheostat (R_1) to its minimum resistance position by turning it completely clockwise. It will be left in this position for the remainder of the experiment.

2. Turn on the power and adjust the load rheostat (R_2) for a minimum load current. Record the data called for on the chart.

3. Increase the load current in 4-ma. steps until the tube goes out, recording current and voltage information at each step.

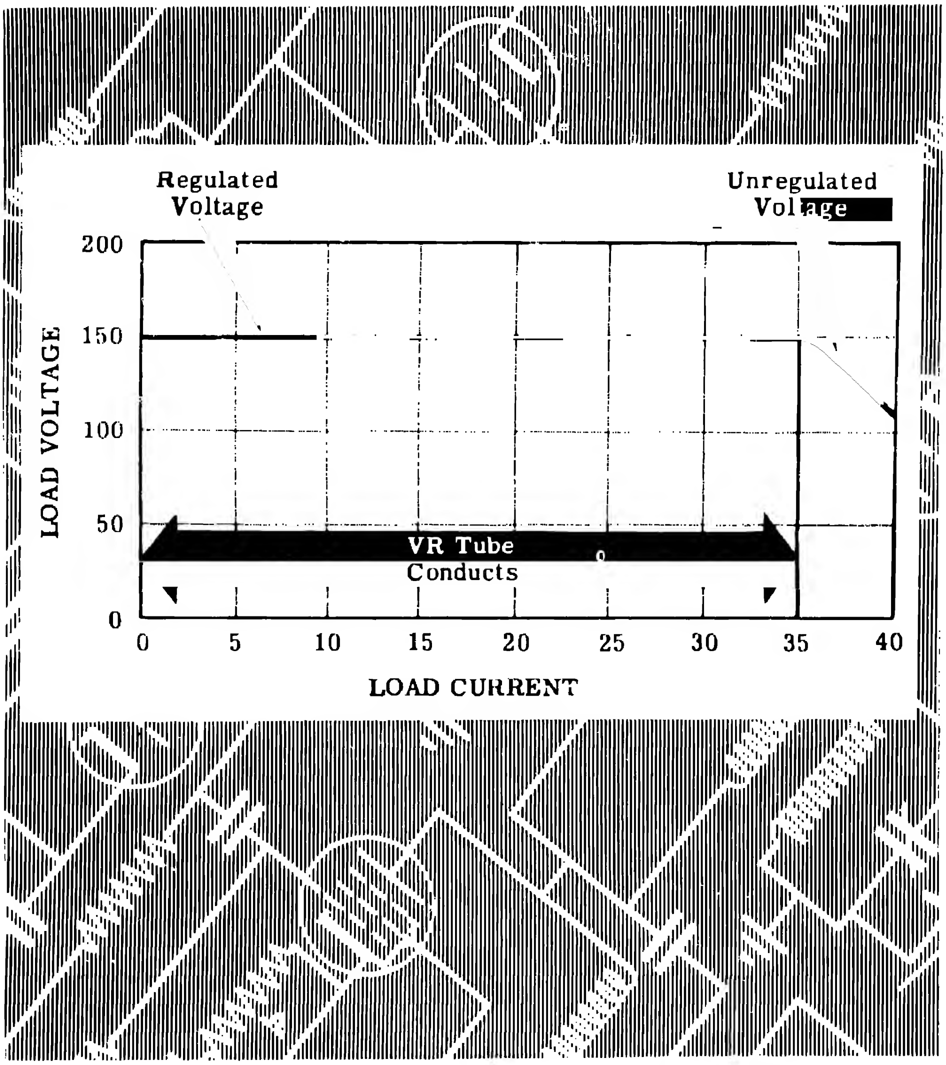


B+ Voltage	Load Current	VR Tube Current	Load Voltage

Experiment—VR Circuit Operation With Varying Load Current (continued)

The illustration below is a graph of typical data obtained from a test such as the one you've just performed. The graph tells you that the load voltage remains constant at 150 volts while the load current varies from zero ma. to about 25 ma. Referring back to your data sheet, you can see that the VR tube current varied considerably within this range. It is these changes in the VR tube current that do automatically what the manually operated rheostat would do. If the VR tube current didn't change, you would not get a regulated voltage output.

The graph tells us that after the VR tube stops conducting (and, of course, there's no change in the tube current) the output voltage is no longer regulated.

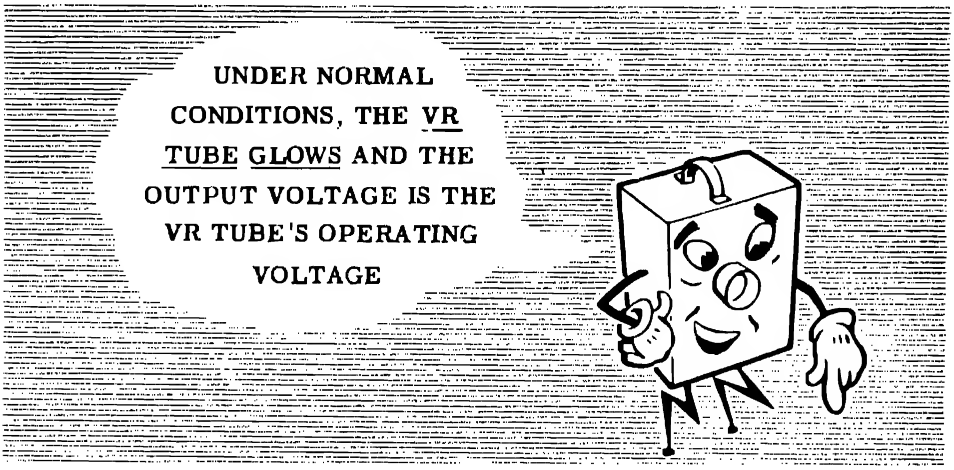


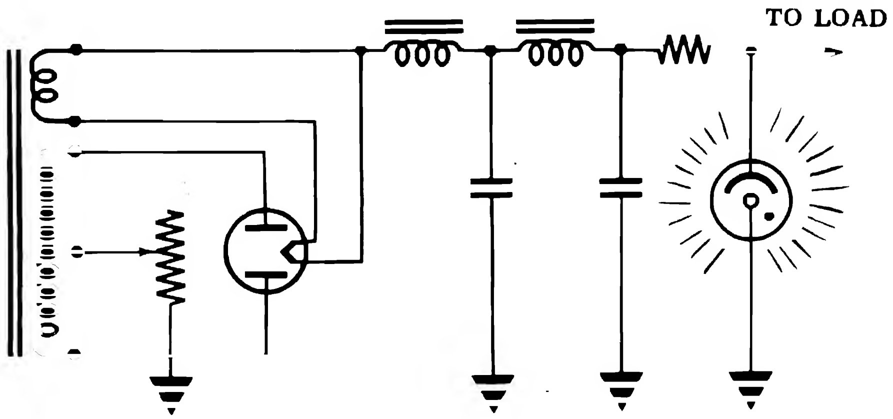
VOLTAGE REGULATOR CIRCUITS

Experiment—Troubleshooting the VR Circuit

The voltage regulator circuit, consisting of the series resistor and VR tube, will very rarely develop trouble. The VR tube is the cold cathode type and therefore, there is no filament to burn out. Most of the troubles that will develop in a voltage regulated power supply are the type that you have studied in your previous experiments in power supplies. The rectifier tube might go bad, or components may become open or shorted.

Troubleshooting the voltage regulator circuit is relatively easy. You know that, when the voltage regulator is working normally, the VR tube will glow. The output voltage will then be the operating voltage of the particular VR tube used.

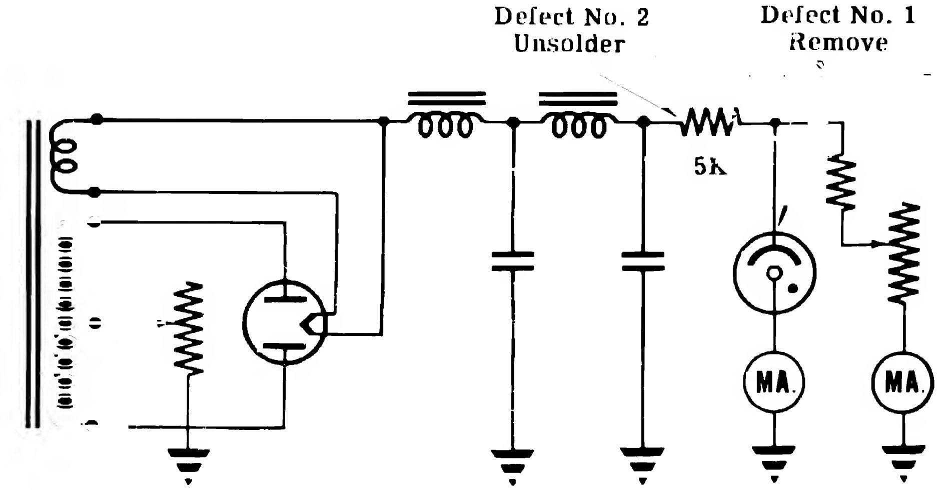




If the voltage regulator circuit is not regulating, the chances are that the VR tube is bad. Replacing the suspected bad VR tube should clear up the trouble.

Experiment—Troubleshooting the VR Circuit (continued)

You are going to place in your circuit the defects listed below. On a separate sheet of paper show how you, as a troubleshooter servicing a piece of equipment, would locate the particular fault.



Defect No. 1

Simulate a faulty OD3 by pulling the VR tube out of its socket. Use a logical troubleshooting sequence imagining that a faulty tube was in the socket.

1. What are the symptoms of this defect?
2. How is the power supply output affected?
3. How do you locate the trouble?

Defect No. 2

Simulate a burned-out 5K resistor by disconnecting the 5K resistor from the B+ lug on the terminal strip.

1. What are the symptoms of this trouble?
2. How is the power supply output affected?
3. Do the filter condensers have discharge paths now?
4. How do you locate the trouble?

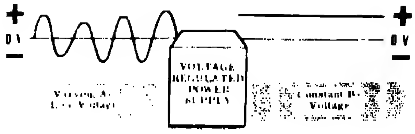
When you have finished troubleshooting your power supply remove the meters from the circuit and disconnect the circuit as follows:

1. Remove the VR tube from its socket and resolder the filament wires to the tube socket.
2. Disconnect the potentiometer (R_1) from terminal 7 of the transformer and remove the potentiometer from the chassis.
3. Disconnect and remove the 3K (5W) resistor.

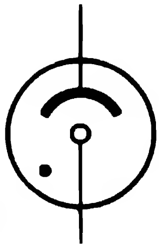
VOLTAGE REGULATOR CIRCUITS

Review

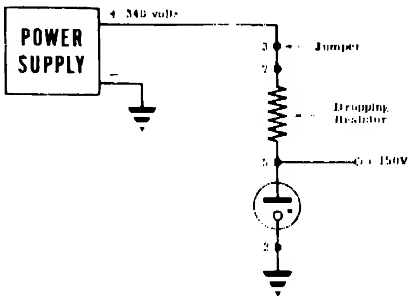
<u>VOLTAGE REGULATION</u> — Voltage regulation is a term used to express how well a power supply maintains a constant voltage output in spite of changes in line voltage and load current. There are certain types of electronic circuits that will not operate properly if the supplied voltage varies more than a few volts. The voltage supply to these circuits requires the addition of a voltage regulator circuit which will maintain an essentially constant voltage regardless of line voltage and load current changes.



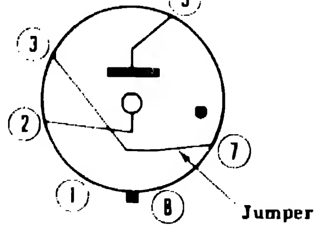
<u>VOLTAGE REGULATOR TUBE</u> — The voltage regulator (VR) tube contains a plate and a cathode with no filament—both enclosed in a glass envelope containing a gas at low pressure. When a large enough voltage is applied across the tube, a current is conducted through the tube. As long as the current flowing through the tube remains within the limits listed by the manufacturer, the voltage at the plate will remain essentially constant.



<u>VR TUBE CIRCUIT</u> -- The simplest (and very widely used) voltage regulator circuit consists of a voltage dropping resistor and a VR tube placed in series across the power supply output and ground. The regulated voltage is taken from the plate of the VR tube. The load current and the VR tube current both flow through the dropping resistor, and the VR tube current changes along with the load current so as to keep the dropping resistor current constant.



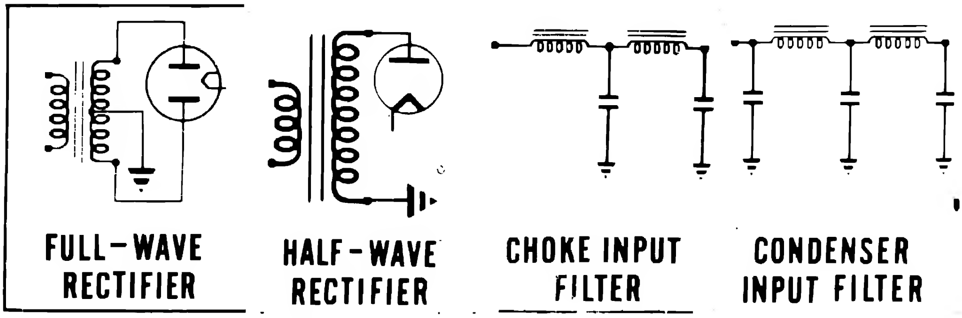
<u>VR TUBE JUMPER</u> — The purpose of the jumper in a VR tube is to prevent unregulated voltage from reaching a special electronic circuit if the VR tube is pulled out. Without the jumper, unregulated voltage would reach the circuit, causing improper operation and possible damage. Pulling out the VR tube removes the jumper and disconnects the voltage from the special circuit.



OTHER TYPES OF POWER SUPPLY CIRCUITS

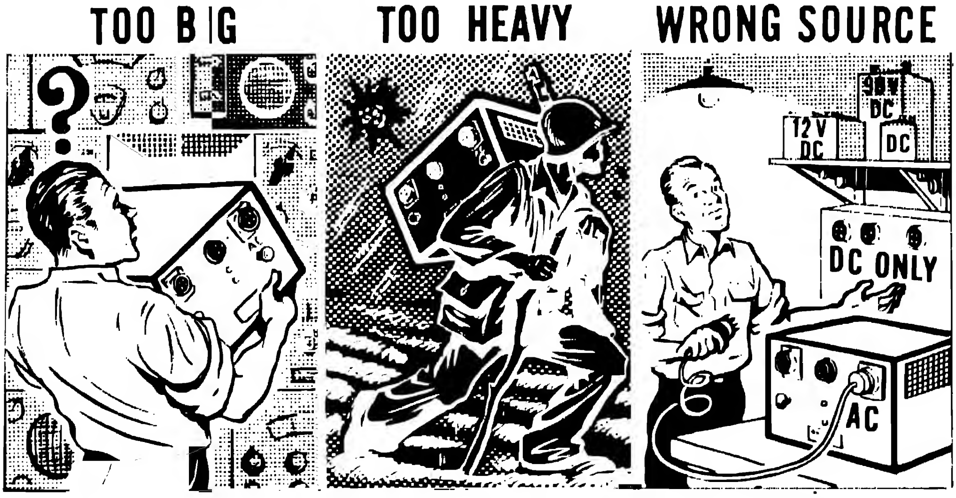
Why the Need for Other Types of Power Supplies

Nearly every power supply you will find in Navy electronic equipment will consist of a half- or full-wave rectifier with a choke or a condenser input filter.



However, there are certain other types of power supplies that will occasionally be found in special types of electronic equipment. These special types of power supplies will be found in equipment upon which are placed size or weight limitations, or limitations as to the type of voltage available from the power line—if a power line is available at all.

Size or weight limitations may require that no transformers or chokes be used in the power supply. In certain cases it may be necessary to eliminate the bulky rectifier tube. There will be cases where AC voltage is not available—requiring the use of a 110 DC line. At some time or another you may even find that 110 DC voltage is not available and only a low voltage DC line or low voltage batteries are available.



The purpose of this portion of the Power Supply Section of Electronic Instruction Sheets is to show you how high voltage DC may be supplied to vacuum tubes under these various restrictions. Since these special types of power supplies are rather rare, you will not need to build them. However you will be required to read the information on the sheets which follow and to discuss these sheets with your instructor. Even though these power supplies are not common, you should know how they work because you are sure to come across at least several of them in the near future. Learn them now and save yourself future headaches.

OTHER TYPES OF POWER SUPPLY CIRCUITS

General Types

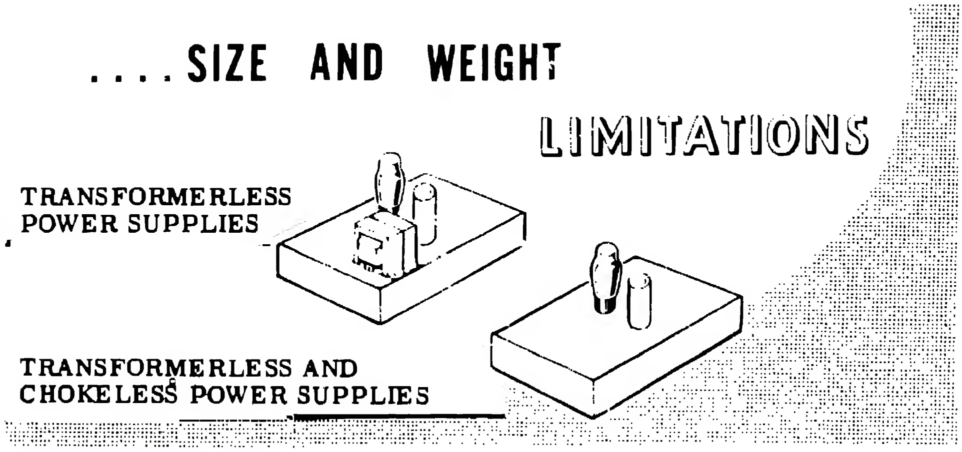
The special types of power supplies you will learn about in the remainder of this topic are divided into two main groups:

1. Power supplies which are included in equipment upon which there are size and weight limitations.

   In this group are included:

   a. Transformerless power supplies

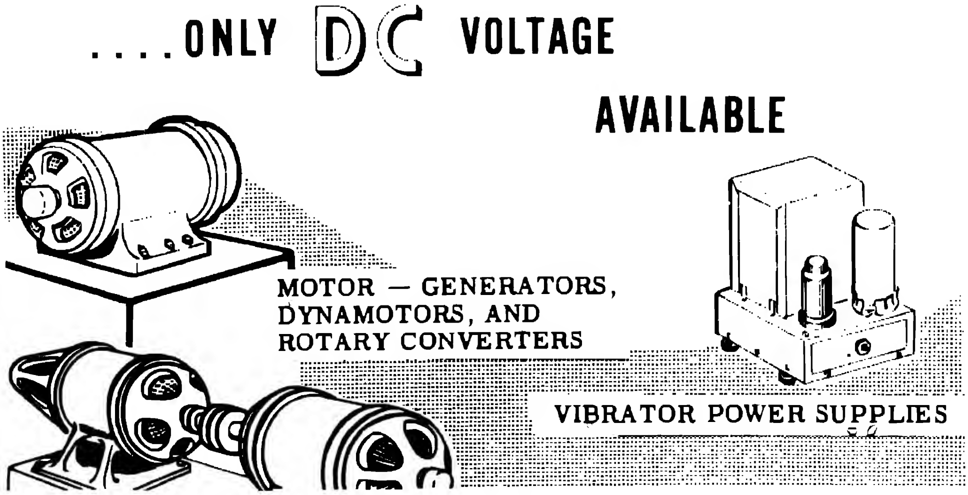
   b. Transformerless and chokeless power supplies



2. Power supplies which are designed for equipment which will have only DC voltage available either from a DC line or from battery sources.

   a. Vibrator power supplies

   b. Motor generators, dynamotors and rotary converters



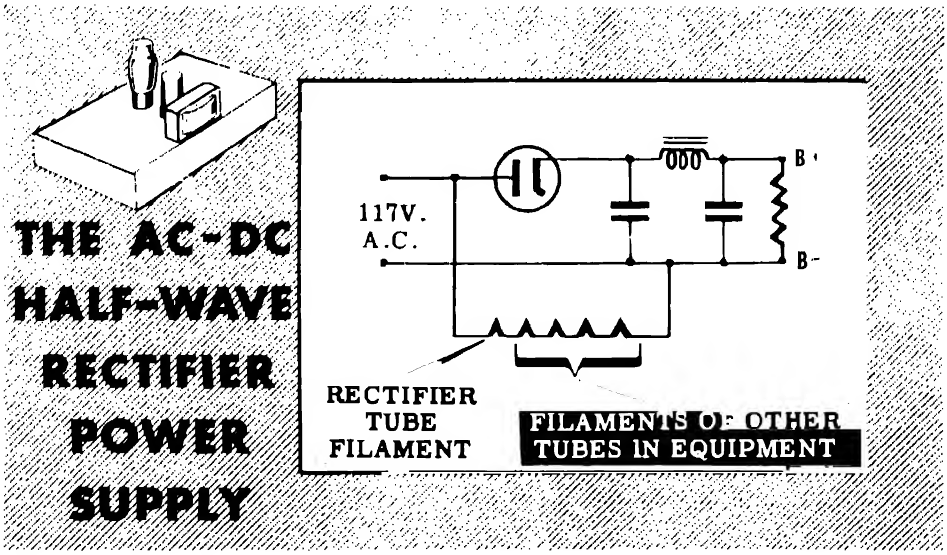
OTHER TYPES OF POWER SUPPLY CIRCUITS

Transformerless Power Supplies

Transformerless power supplies are sometimes used in Navy Electronic equipment to save the weight and space of the power transformer. In commercial radios, transformerless power supplies are very often used to save the cost of the transformer as well as to save the space and weight. Nearly any portable radio that you may look into will have a transformerless power supply, and many "console" model radios are made that way too. There are three types of transformerless power supplies in general use—the AC-DC half-wave rectifier, the voltage doubler and the dry metal rectifier power supplies.

The AC-DC Half-Wave Rectifier Power Supply

The AC-DC half-wave rectifier power supply is useful only in circuits where the tubes will operate at about 100 volts B+ and with tubes that have high voltage filaments. This circuit will supply about 100 volts B+ and will operate either on AC or DC. The circuit itself is a simple half-wave rectifier circuit usually followed by a condenser input filter—you are acquainted with the operation of both these circuits.



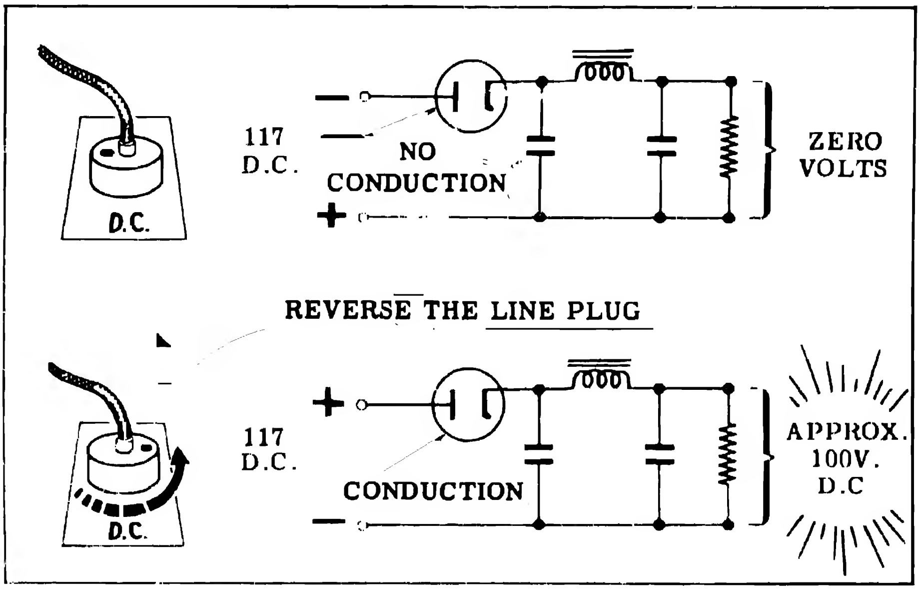
Notice that the filaments of the rectifier tube and the other tubes in the circuit are all connected in series across the power line. As long as all the tubes have the same filament current requirement and as long as the filament voltages add up to approximately the line voltage, the circuit will operate properly. A typical 5-tube portable radio would use a 35Z5 rectifier tube; a 12SA7 first detector, a 12SK7 IF amplifier, a 12SQ7 second detector and a 50L6 audio amplifier. The filament voltages required by these tubes add up to 121 volts ($35 + 12 + 12 + 12 + 50 = 121$) which is close enough to the line voltage.

OTHER TYPES OF POWER SUPPLY CIRCUITS

Transformerless Power Supplies (continued)

The AC-DC Half-Wave Rectifier Power Supply (continued)

One special thing about this power supply is that it will operate on either AC or DC. If a transformer were included in the circuit, the transformer would burn out (or a protecting fuse would blow) in the event that it was connected to a DC line. In the AC-DC half-wave power supply there is no transformer. When the plate of the rectifier tube is connected to the positive side of a DC line and when the cathode is connected to the negative side of the DC line through the load, the circuit will supply B+ voltage. The rectifier plate will always be positive with respect to the cathode, and a steady stream of electrons will be attracted to the plate—a B+ voltage with very little ripple will appear at the cathode.



Notice that for DC line operation the plate must always be connected to the positive side of the line and the cathode must always be connected through the load to the negative side of the line. If these connections should be reversed accidentally (because of the use of a non-polarized line plug), the plate of the rectifier will be negative and will attract no electrons from the cathode. The circuit will not work. Whenever a power supply of this type does not operate on a DC line, one of your first checks should be to pull out the line plug and turn it so as to reverse the rectifier tube connections to the line. The use of a polarized line and line plug prevents this trouble.

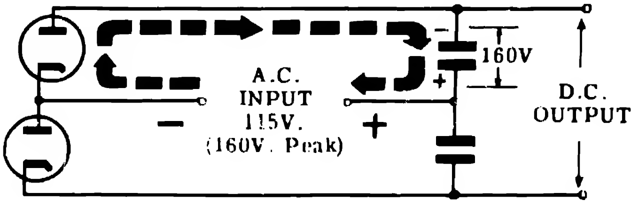
If an AC line is used, this power supply will operate no matter how the line plug is connected to the line. However, one side of the AC line is usually grounded and one side is "hot." If the rectifier is plugged in so that the cathode is connected to the "hot" side of the line through the load, there will be more AC hum in the circuit attached to the power supply. Whenever you notice excessive hum in equipment using a power supply of this type, try reversing the line plug. The use of a polarized line and line plug will prevent this trouble.

Transformerless Power Supplies (continued)

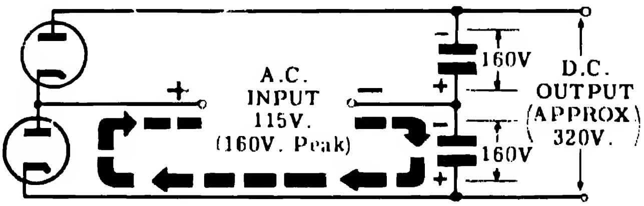
The Voltage Doubler Power Supply

A transformerless type of power supply which is sometimes used in Navy and commercial electronic equipment is the voltage doubler. The disadvantage of the AC-DC half-wave power supply is that it will furnish only about 100 volts B+ which places great restrictions upon the type of circuits which may use this power supply. Voltage doublers do away with this problem by supplying approximately 300 volts B+ when connected to a 110-volt AC line.

THE VOLTAGE DOUBLER



D C OUTPUT = TWICE PEAK A C INPUT



The operation of a voltage doubler circuit is very simple and is shown in the illustration. This circuit uses a rectifier containing two plates and two cathodes—giving you two half-wave rectifier circuits. Each of the two half-wave rectifiers operates off the same AC input. When the right-hand AC input terminal is positive, the upper rectifier in the diagram conducts electron current and the upper condenser charges up to peak line voltage. When the left-hand AC input terminal is positive, the lower rectifier in the diagram conducts electron current and the lower condenser charges up to peak line voltage. Each condenser is now charged and both are in series with respect to the DC output terminals. The sum of these two peak voltages is now available as a DC output which is equal to twice the peak voltage of the AC input.

In circuits of this type the heaters of the rectifier tube and the other tubes in the circuit are all connected in series in the same way as with the AC-DC half-wave rectifier. The voltage doubler will operate only when connected to an AC line since the doubling effect is due to the reversal in line voltage. The voltage doubler circuit sometimes has a transformer between the line and the AC input terminals of the doubler circuit. The transformer is used either to isolate the circuit from the ground of the AC line or to put a higher AC voltage into the circuit so as to get a very high voltage DC output.

OTHER TYPES OF POWER SUPPLY CIRCUITS

Transformerless Power Supplies (continued)

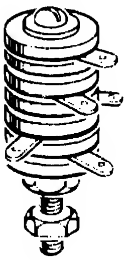
Dry Metal Rectifier Power Supplies

In an earlier experiment in this section of Electronics Instruction Sheets, you learned how dry metal rectifier circuits worked. Dry metal rectifiers allow you to eliminate the transformer in an electronic power supply. Dry metal rectifiers have the advantage of being rugged, long-lived, small in size and capable of large current output. They are quite adaptable to being hooked up in half-wave, full-wave and voltage doubler circuits. They also can be hooked up to give either a positive or negative voltage output.

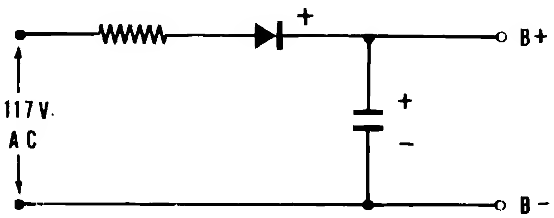
Dry metal rectifiers are used to some extent in radar, sonar and communications equipment. In addition they are also used as the rectifier in AC voltmeters. A few common circuits that contain dry metal rectifiers are shown below. Since you are already acquainted with both the dry metal rectifier and the circuits themselves, you should be able to understand how these circuits work without further explanation.

When power is first applied, a high current will flow to charge the input condenser. You will notice that a resistor (R) is inserted in series with each half-wave rectifier element. This resistor is put in as a current limiting device to prevent too much current from flowing through the rectifier.

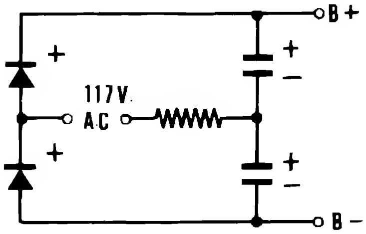
BRIDGE TYPE RECTIFIER



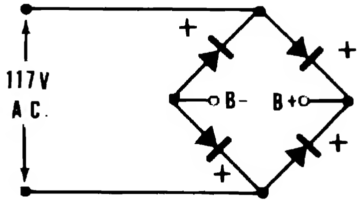
HALF-WAVE DRY METAL RECTIFIER CIRCUIT



VOLTAGE DOUBLER CIRCUIT



BRIDGE RECTIFIER

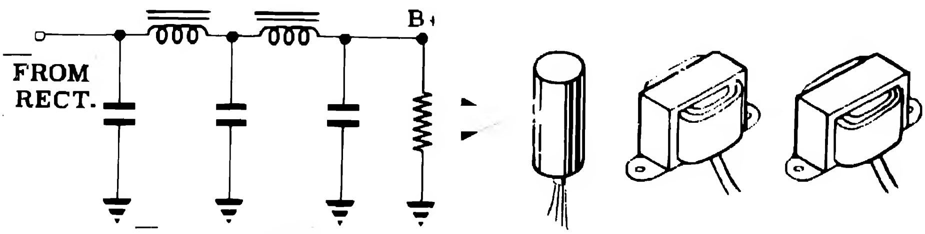


OTHER TYPES OF POWER SUPPLY CIRCUITS

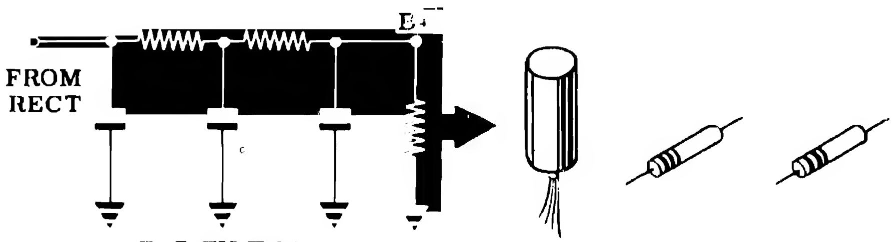
Transformerless and Chokeless Power Supplies

Eliminating the choke as well as the transformer from the power supply results in the savings of weight, space and cost. The choke may be eliminated from the filter circuit by replacing it with a resistor. The result is a resistance-capacitor (RC) filter as shown in the illustration. RC filters are economical and work very well whenever the load current drawn from the filter circuit is small. RC filters are used extensively in oscilloscopes, vacuum tube voltmeters and other equipment that require very little B+ current drain.

PARTS USED:



L-C FILTER



R-C FILTER

The advantage of the RC filter is its savings in weight, space and cost. The disadvantage is that the filtering action is effective only with small B+ current drain. As you remember from your experiments with filter circuits earlier in this section, a choke presents a high impedance to the AC ripple coming out of the rectifier and the condenser presents a low impedance. As a result, most of the ripple will appear across the choke and very little will appear across the condenser and the load. The DC voltage, however, is not presented with any impedance by the choke other than the resistance of the winding which is very low.

The RC filter offers the same resistance to both the AC ripple and the DC current. As a result there is a drop in DC voltage caused by the DC current flow through the filter resistor. If the value of the resistor is made low to decrease the DC voltage drop, ripple voltage will get through the filter. If the value of the resistance is increased to stop the AC ripple, the drop in DC voltage will be too great. The only way to make this type of filter operate efficiently is to use a large value of resistance to draw very little DC current from B+. Very little DC current flowing through the high value of resistance means that there will be a very small DC voltage drop across the resistor and the filter will operate efficiently.

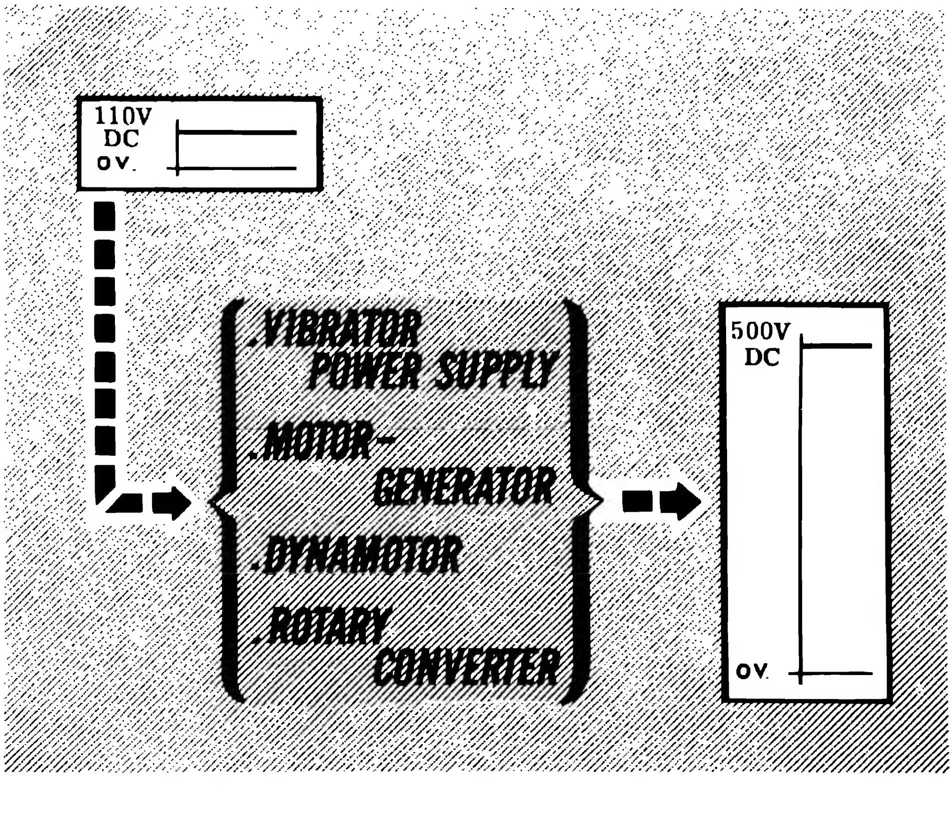
OTHER TYPES OF POWER SUPPLY CIRCUITS

Power Supplies for DC Voltage Sources

Now that you know something about power supplies that are specially designed to save weight and space (and cost in commercial applications), you are ready to find out something about power supplies that are designed to operate electronic equipment when only DC voltage is available.

In order to operate electronic equipment properly, a fairly high DC voltage is required for the various vacuum tubes in the equipment. When an AC line is available, it is a simple matter to step up the available AC voltage by means of a transformer and rectify the resulting high voltage AC into high voltage DC. You have seen that when space and weight restrictions are important, power supplies may eliminate the transformer and put out a DC voltage of approximately 100 volts B+. You have also seen low-**voltage doubler circuits can give you a B+ voltage twice the peak value of the AC line without the use of a transformer.**

You are now ready to find out how high voltage DC can be supplied to electronic circuits when the only source of voltage is DC at 110 volts or lower voltage sources such as batteries. The general solution to this problem is to change the DC to AC, which can then be stepped up in voltage and then rectified into high voltage DC. This is done by means of vibrators, motor generators, dynamotors and rotary converters. When DC voltage at approximately 110 volts is available and if a B+ voltage output of 100 volts is satisfactory, the AC-DC half-wave rectifier power supply already described may be used.



OTHER TYPES OF POWER SUPPLY CIRCUITS

Vibrators

The vibrator type power supply changes low voltage DC from batteries or a DC line into high voltage DC by means of three operations:

1. The low voltage DC is changed into AC of the same voltage.

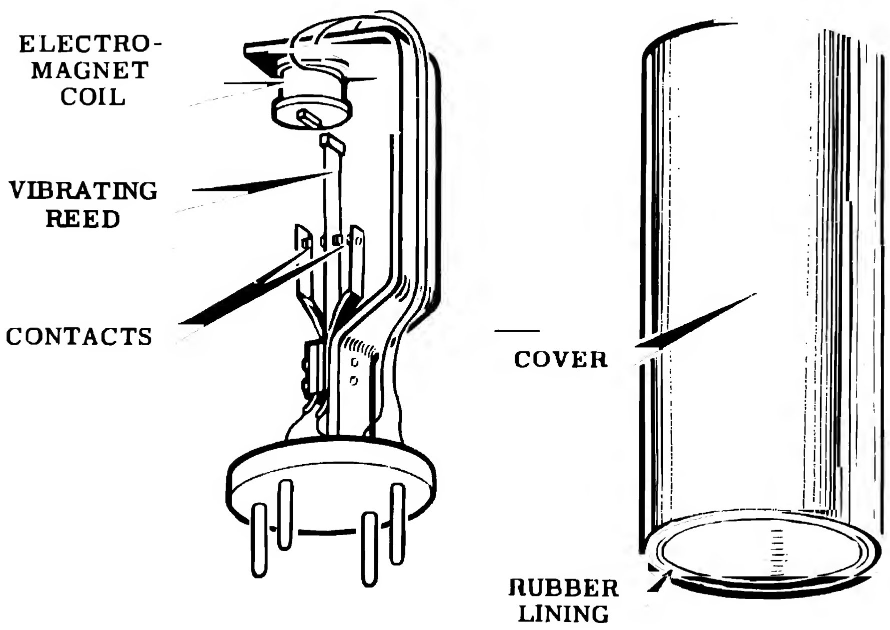
2. The low voltage AC is put into a transformer and comes out as high voltage AC.

3. The high voltage AC is rectified and filtered into high voltage DC.

The vibrator is the means by which the first operation is accomplished. Operation 2 is accomplished by means of a transformer. Operation 3 is done by means of either the vibrator or one of the conventional vacuum tube rectifier and filter circuits with which you are already familiar.

The construction of a simple vibrator is shown below. A heavy strip of metal serves as a frame to hold a small electromagnet, a spring metal "reed" and two electrical contacts in place. A soft-iron tip is mounted on the free end of the reed, near the electromagnet. The electromagnet is mounted slightly off-center so that it can move the reed whenever current flows in the coil of the electromagnet. This vibrator mechanism is inserted in a metal cover which is often lined with a vibration absorbing material such as soft rubber.

What goes on inside the VIBRATOR!



OTHER TYPES OF POWER SUPPLY CIRCUITS

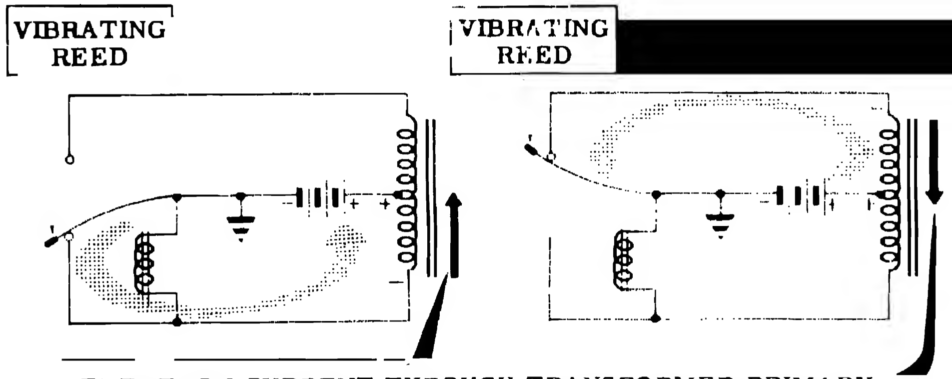
Vibrators (continued)

The vibrator you saw on the last sheet is connected to the primary winding of a transformer as shown in the illustrations on this sheet. For the moment ignore the transformer secondary circuit and just consider what takes place in the primary circuit. Before the DC source—here shown as a battery—is connected into the circuit, the reed remains between the two contacts. When the battery is put into the circuit, the following things happen:

1. **A small DC current flows from the battery through the electromagnet, through the lower half of the transformer primary and back into the battery.**

2. The electromagnet builds up a magnetic field and attracts the reed towards the lower contact.

3. The reed strikes the lower contact and a large DC electron current flows from the battery through the reed, through the lower contact, through the lower half of the transformer primary and back into the battery.



ELECTRON CURRENT THROUGH TRANSFORMER PRIMARY

When the vibrator reed hits the lower contact, it puts a direct short across the electromagnet coil. This causes the magnetic field to collapse. Since the electromagnet can no longer hold the reed against the lower contact, the reed springs back past the center position and strikes the upper contact. When the reed strikes the upper contact, the following things happen.

4. A large DC electron current flows from the battery through the reed, through the upper contact, through the upper half of the transformer primary and back into the battery.

5. Since the electromagnet is no longer shorted out by the reed, it builds up a magnet field and pulls the reed back towards the lower contact.

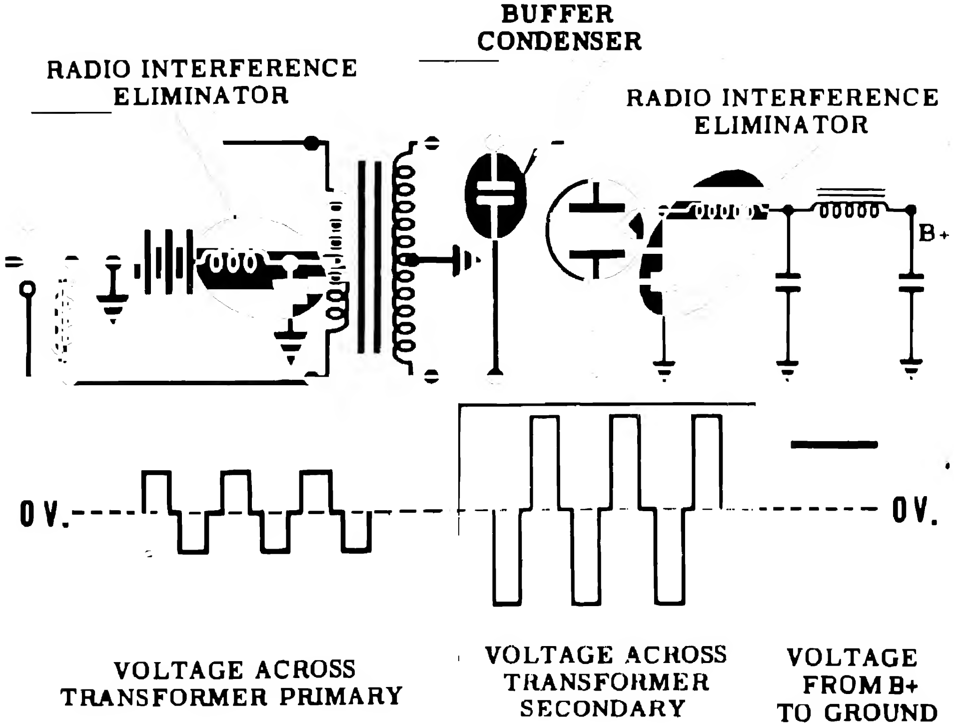
The entire cycle is repeated again and again. Vibrations take place at approximately 100 times per second.

OTHER TYPES OF POWER SUPPLY CIRCUITS

Vibrators (continued)

The net result is an AC current that flows through the primary of the transformer, first in one direction and then in the opposite direction. This reversal of current, induces high voltage in the transformer secondary. This high voltage is rectified by a vacuum tube rectifier circuit and becomes high voltage DC. The fact that this high voltage DC has square topped peaks instead of the usual sine wave shape does not matter—the filter circuit circuit changes it into a smooth B+ voltage.

The type of vibrator used in this circuit is known as a "non-synchronous" vibrator.



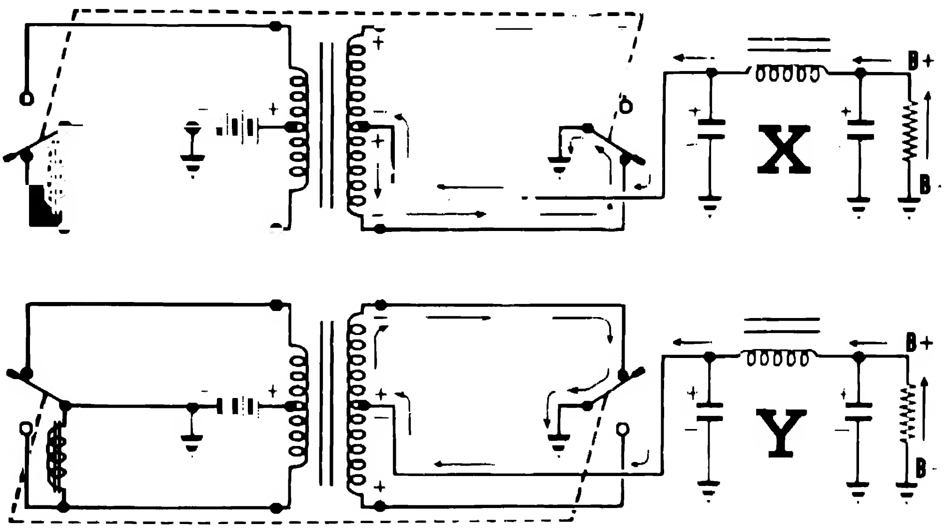
Because of the very sharp voltage surges occurring in the vibrator power supply circuit, various difficulties are experienced with this type of circuit. One annoying trouble is sparking at the vibrator contacts due to the very high voltage induced in the secondary at the instant the reed separates from the contacts. This sparking shortens the life of the vibrator, but it may be eliminated to a large extent by inserting a buffer condenser across the secondary to short out the sharp voltage pulses. This condenser has a fairly critical value, usually in the range of from 0.0005 to 0.05 microfarads. The buffer condenser reduces sparking so that the life of the vibrator contacts will not be shortened; however, any remaining sparking may cause radio interference. This radio interference is eliminated by the addition of RF chokes and condensers in the transformer primary center tap and in the rectifier output.

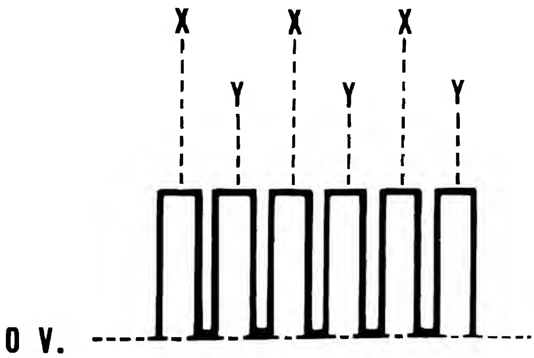
OTHER TYPES OF POWER SUPPLY CIRCUITS

Vibrators (continued)

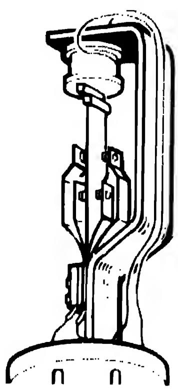
Another type of vibrator circuit is one that makes use of the vibrating reed to rectify the high voltage AC from the transformer secondary into pulsating DC without the use of a separate rectifier. This circuit is known as the "synchronous" vibrator circuit. The portion of the circuit in the transformer primary works exactly the same as in the non-synchronous vibrator circuit. The transformer secondary is connected back to the vibrator reed by means of an extra pair of contacts as shown in the diagram.

THE Synchronous Vibrator





B+ OUTPUT FOR CONDITIONS X AND Y



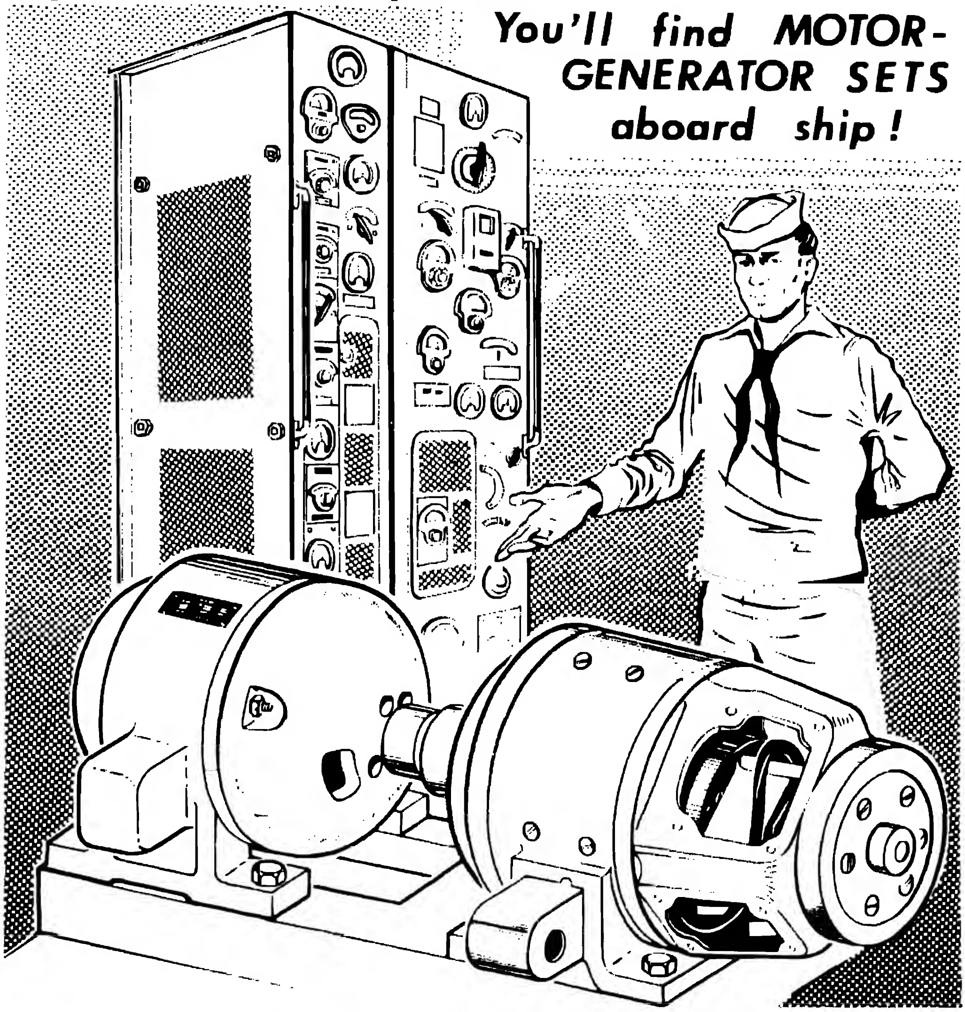
The two vibrating reeds shown connected together by the dotted line in the diagram are actually one reed placed between two pairs of contacts. The action of the reed between the transformer secondary contacts produces the same results as a full-wave rectifier. RF chokes and buffer condensers are used in this vibrator circuit in the same manner as in the non-synchronous vibrator to eliminate contact sparking and radio interference.

OTHER TYPES OF POWER SUPPLY CIRCUITS

Motor Generators, Dynamotors and Rotary Converters

For some applications, such as in radio transmitter equipment, electronic power supplies cannot supply the large amounts of DC power which are required. For large power requirements, motor-generator sets replace the more common electronic power supplies.

The motor runs off the ship's power lines and is either a DC or AC motor depending on the nature of the ship's power. This motor is mechanically coupled to the generator which is always DC when used as a power supply. The generator output voltage may be as high as 3,000 volts. An electronic power supply capable of such high voltages would not be able to supply as large currents as could a DC generator.

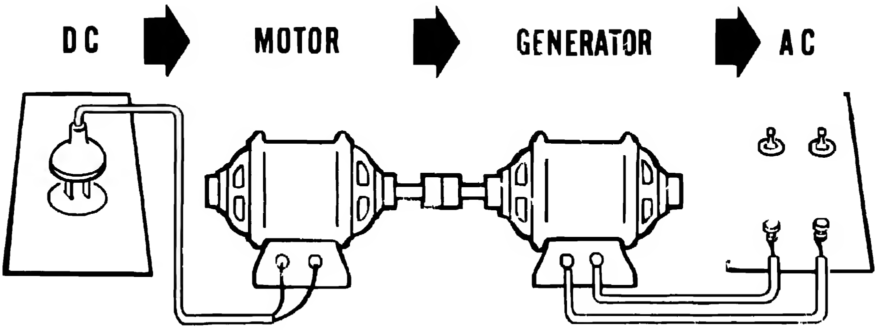


Your assignment after the completion of this course may bring you into contact with equipment using motors and generators. If so, it will be your responsibility to keep them operating smoothly and to detect any trouble in the rotating machinery as soon as it occurs. In this way, there will be fewer major repair jobs and your equipment will be useful more of the time.

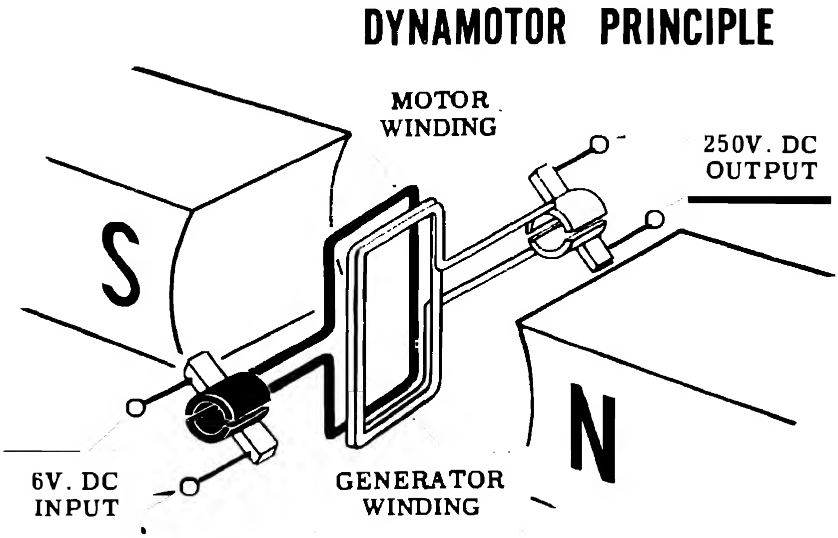
OTHER TYPES OF POWER SUPPLY CIRCUITS

Motor Generators, Dynamotors and Rotary Converters (continued)

Motor generators, dynamotors and rotary converters are sometimes used to operate AC electronic equipment when only a DC source of voltage is available. A motor generator consists of a motor and a generator mechanically connected together. For the application being considered a DC motor would be used to drive an AC generator which would be designed to give a 60-cycle output at line voltage. Equipment designed to operate from 60-cycle AC at line voltage could then be operated from a DC source by means of this type of motor generator. This type of motor generator could be used as an emergency unit by having the equipment operate off the AC line under normal conditions, and the equipment could operate from a battery source by means of the motor generator in the event of an AC line failure.

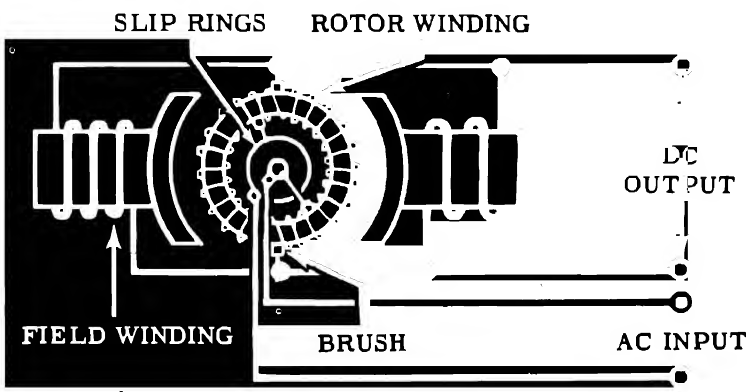


A dynamotor is a rotating DC machine that operates from a low voltage DC source and puts out one or several high voltage DC outputs. It is basically a DC motor and a DC generator built onto one armature and having two or more windings and two or more commutators. Dynamotors are usually operated from 6-, 12-, 24- or 32-volt storage batteries and deliver from 250 to over a thousand volts DC at various current ratings.

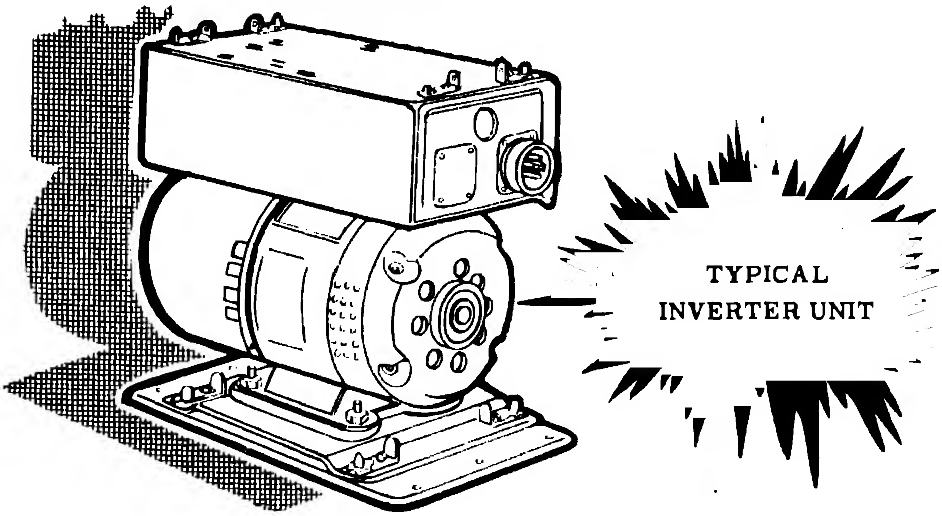


Motor Generators, Dynamotors and Rotary Converters (continued)

Rotary converters are commonly used to change AC to DC, but they may be used to operate off storage batteries and give an output of 60 cycles AC at line voltage. When used to operate from DC sources and give AC outputs, they are known as inverters. The construction of a rotary converter is similar to a DC generator except that two slip rings are used which are connected to commutator segments 180 degrees apart.



SIMPLIFIED SCHEMATIC DIAGRAM OF ROTARY CONVERTER

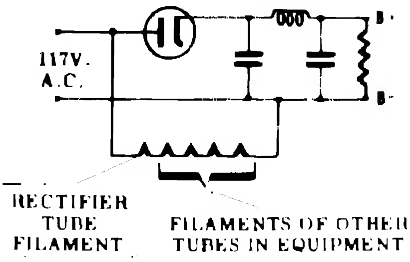


When the peak AC voltage output desired is no higher than the average DC voltage input, one winding may be used on the armature. If a greater voltage is desired, two windings are used on the same armature. The use of one armature and one field for both the AC and DC sections results in instability of operation. In order to increase stability the AC and DC sections are often wound on two armatures using separate fields. The two armatures are coupled together and the whole unit functions as a motor and a generator built into one unit.

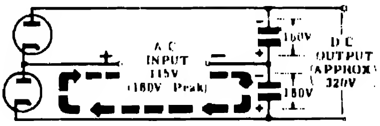
OTHER TYPES OF POWER SUPPLY CIRCUITS

Review of Transformerless Power Supplies

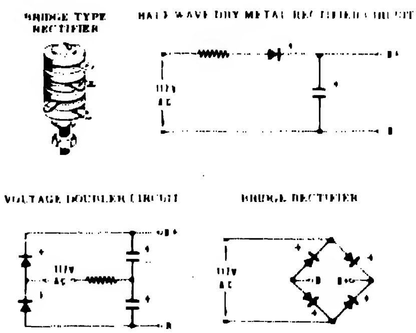
<u>AC-DC HALF-WAVE RECTIFIER POWER SUPPLY</u> — This circuit will supply about 100 volts B+ and will operate from either in AC or DC power line. The circuit is a simple half-wave rectifier circuit usually followed by a condenser input filter. The filaments of the rectifier tube and the other tubes in the circuit are all connected in series across the power line.



<u>VOLTAGE DOUBLER POWER SUPPLY</u> -- This circuit will supply up to 320 volts B+ from a 117-volt AC power line without the use of a transformer. The circuit consists of two half-wave rectifiers and two capacitors. The capacitors are connected in series and each is charged up to peak line voltage resulting in the voltage doubling effect. The filaments of the rectifier tube and the other tubes in the circuit are all connected in series across the power line.

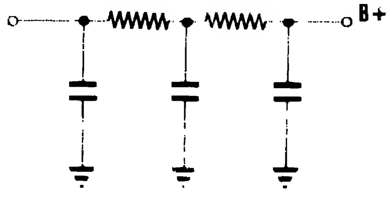


<u>DRY METAL RECTIFIER POWER SUPPLY</u> — Dry metal rectifiers may be used instead of vacuum tube rectifiers. Dry metal rectifiers are rugged, long-lived, small in size and capable of large current output. They can be hooked up in half-wave, full-wave and voltage doubler circuits.



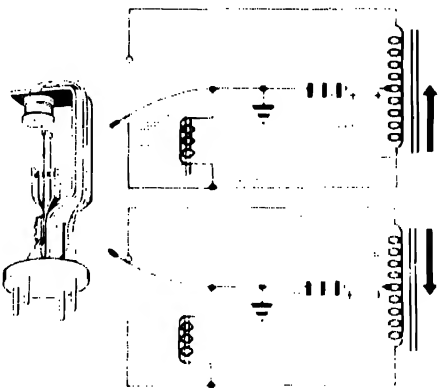
OTHER TYPES OF POWER SUPPLY CIRCUITS

Review of Transformerless and Chokeless Power Supplies

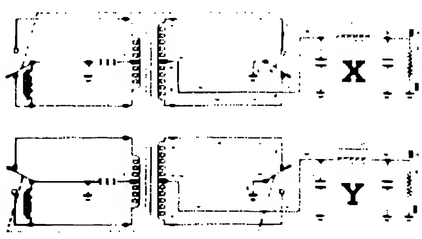


CHOKELESS POWER SUPPLIES — Any of the transformerless rectifier circuits listed on the previous sheet may be used with standard choke and capacitor filter circuits. However, an additional savings may be made in space, weight and cost if the filter choke is replaced with a resistor. This type of RC filter is effective only when a very small B+ current drain is required and a fairly large resistor can be used.

Review of Power Supplies for DC Voltage Sources



VIBRATORS — A vibrator is a mechanical device which changes DC into AC. A simple vibrator is essentially a single pole double throw switch with a vibrating switch arm. When the vibrator is connected to a transformer with a center tapped primary as shown, the action of the vibrating switch arm causes current to flow first in one direction and then in the other direction through the transformer primary. The transformer puts out an alternating high voltage which can be rectified and filtered into a high voltage DC.

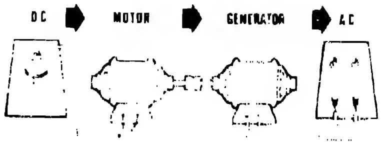


SYNCHRONOUS VIBRATORS — The non-synchronous vibrator changes DC into high voltage AC which must then be rectified by means of a vacuum tube rectifier. A synchronous vibrator does away with the need for a separate rectifier. The portion of the vibrator in the transformer primary works exactly as in the non-synchronous vibrator circuit. The transformer secondary is connected back to the vibrator reed by means of an extra pair of contacts as shown. The action of the vibrating reed between the transformer secondary contacts produces results the same as if a full-wave rectifier were placed there.

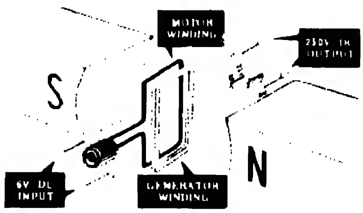
OTHER TYPES OF POWER SUPPLY CIRCUITS

Review of Power Supplies for DC Voltage Sources (continued)

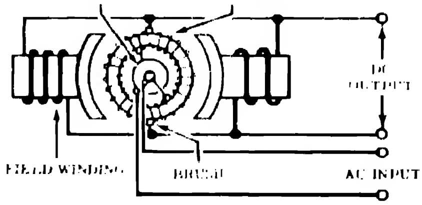
MOTOR GENERATOR — A motor and a generator mechanically coupled together. Equipment designed to operate from an AC power source may be made to operate from the DC line if a motor generator is used. The DC motor is connected to the DC line, and the DC motor spins the rotor of the AC generator which puts out 117 volts AC.



DYNAMOTOR — A rotating DC machine that operates from a low voltage DC source and puts out one or more high DC voltages. A dynamotor is basically a DC motor and a DC generator built onto one armature and having two or more commutators.



ROTARY CONVERTER — Rotary converters are commonly used to change AC to DC, but they may be used to operate from storage batteries to give an output of 117 volts AC and are then known as inverters. The construction of a rotary converter is similar to a DC generator except that two slip rings are used which are connected to commutator segments 180 degrees apart.



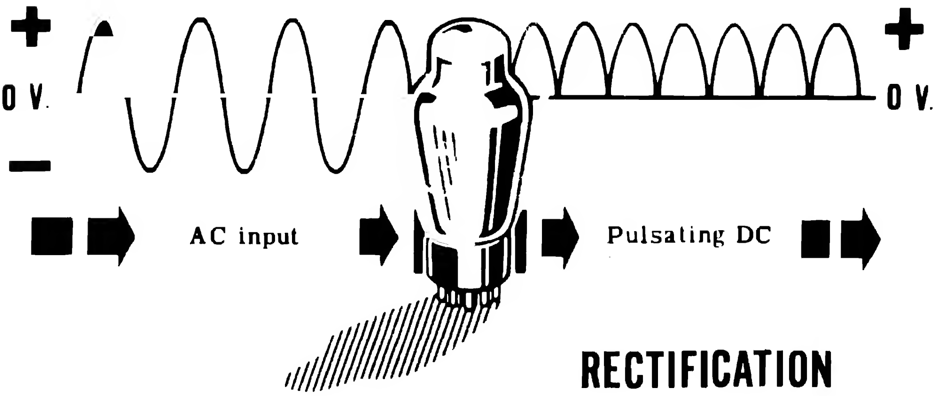
CHARACTERISTICS OF DIODE VACUUM TUBES

The Jobs of a Vacuum Tube

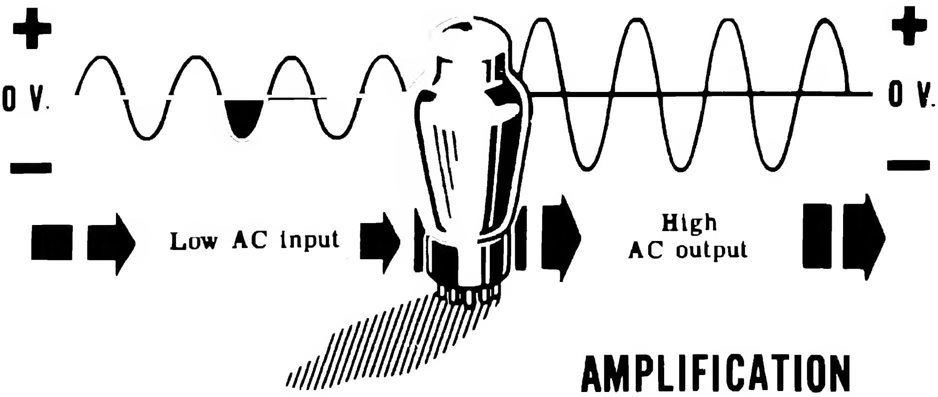
Up to this time you have been working with vacuum tubes used as rectifiers in power supply circuits. Your knowledge of diode tubes has been sufficient for an understanding of power supplies. However, from now on you are going to do a great deal of work with vacuum tubes in many types of circuits, and now is the time to begin finding out about vacuum tubes.

The subject of vacuum tubes is really a simple one because—and you will be glad to know this—vacuum tubes do only two types of jobs.

A vacuum tube can change an AC voltage into a pulsating DC voltage. This is called RECTIFICATION. This job is accomplished by the diode.



A vacuum tube can change a small AC voltage into a large AC voltage. This is called AMPLIFICATION. This job is done by the triode, the tetrode or the pentode.



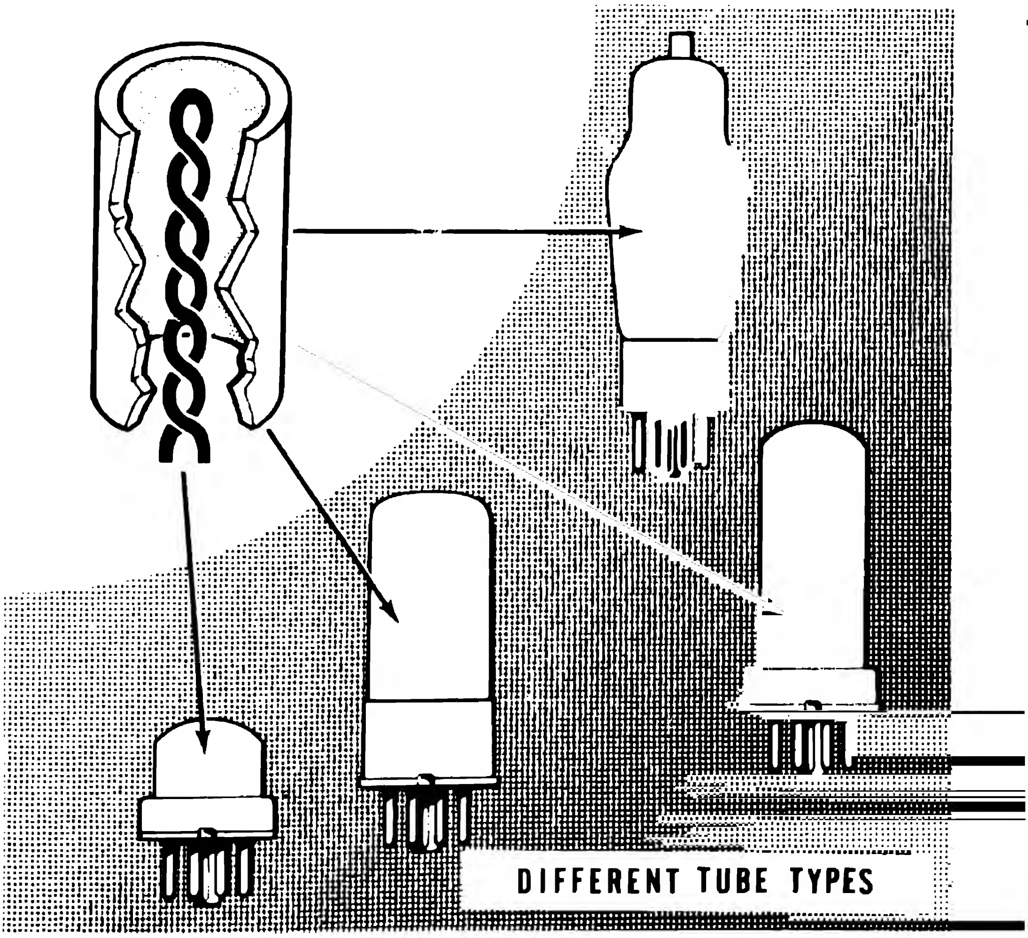
You have been concerned with the vacuum tubes that take care of rectification. Later, in the amplifier section, you will learn about the other types of vacuum tubes.

CHARACTERISTICS OF DIODE VACUUM TUBES

Factors Common to All Vacuum Tubes

The diode is one of the four basic types of vacuum tubes. There are many things which are common to all vacuum tubes and you won't have to learn all about these common characteristics each time you study another type of tube. You will learn about these things in your study of the diode.

As previously stated, all vacuum tubes need a source of free electrons and you will find that each type of tube obtains them in the same way as the diode—by thermionic emission. Furthermore, the cathode and filament structure does not differ very much from one type of tube to the next. You will study the effects of the filament on cathode emission only during your diode experiment—remember, it's the same for the other tubes you will study.



The differences between the diode and the other vacuum tubes lead to their different uses. The diode is used to change an AC voltage into a pulsating DC voltage; the other tubes are used to change a small AC voltage into a large AC voltage. You will see how each tube does its job when you test it.

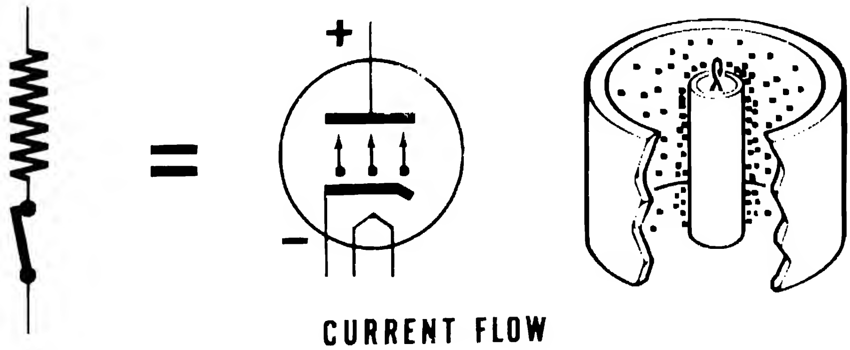
CHARACTERISTICS OF DIODE VACUUM TUBES

Review of Diode Characteristics

Before you actually get into the testing procedure, let's review a few things about diodes, what they do and how they do it, so that you'll have a clear idea of what to look for in these tests.

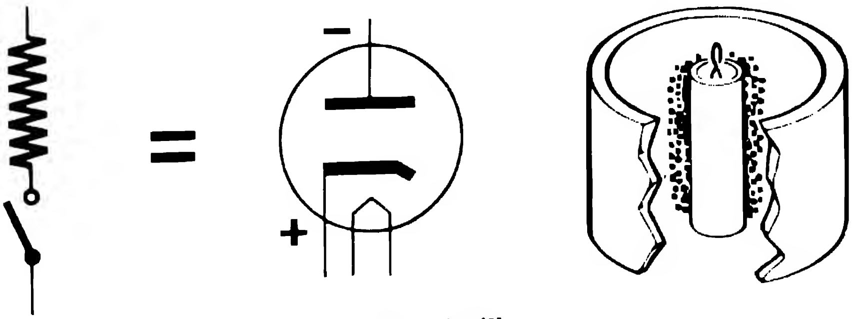
Diodes are used as rectifiers in power supplies, and as detectors, noise limiters and automatic volume control tubes in radio receivers. Whatever their application is, however, diodes are used because they allow current to flow in only one direction.

From the time the plate becomes just slightly positive with respect to the cathode until the time saturation is reached, the current in the diode is proportional to the plate voltage. Between these limits, then, the tube acts the same as an ordinary resistor. Of course, when the plate voltage rises above the saturation point, the current does not respond to voltage changes and therefore, in this region, the tube loses its resemblance to the resistor.



CURRENT FLOW

When the plate becomes the least bit negative with respect to the cathode, no electrons will flow from the cathode to the plate. The tube acts as if it were a resistor in series with a switch and the switch were opened up.

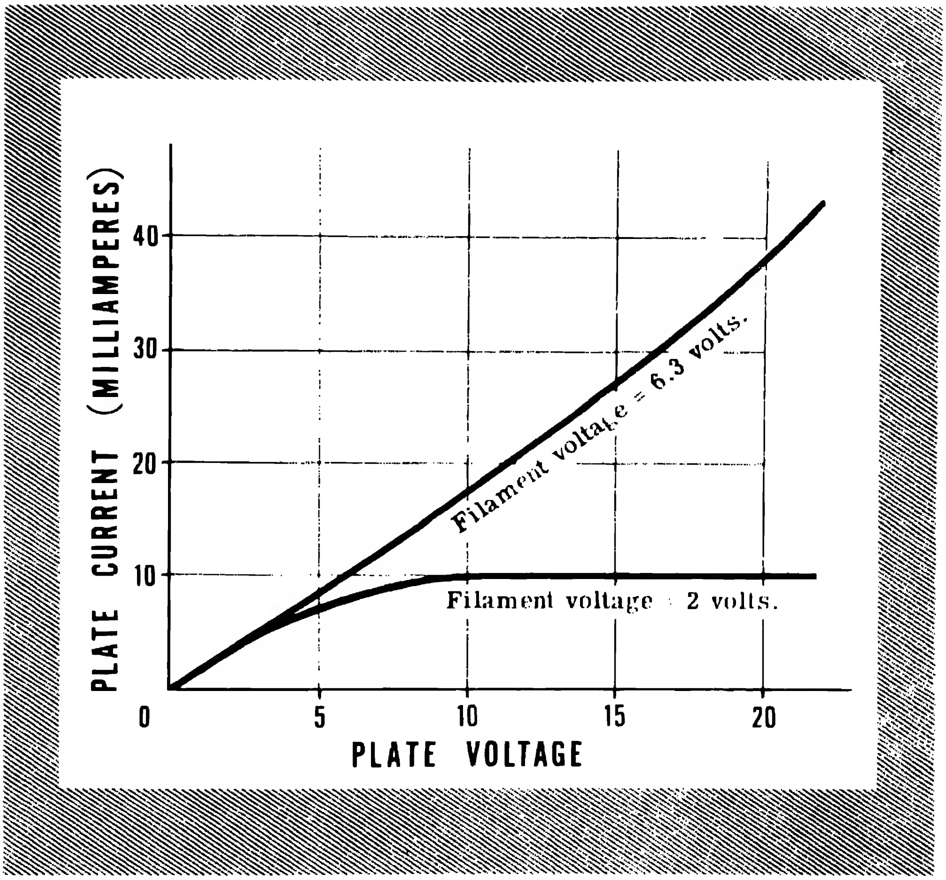


NO FLOW

CHARACTERISTICS OF DIODE VACUUM TUBES

How Current Is Controlled in a Diode

A simple way to show how a diode will respond to changes of voltage is with a graph. A graph picturing how a typical diode's current is affected by its plate-to-cathode voltage (at two different values of filament voltage) is shown below.



From a quick look at the graph you can tell that:

1. At normal filament voltage (6.3 volts), the plate current increases steadily as the plate voltage is increased from zero to 20 volts.

2. At the lower value of filament voltage (simulating the effect of an old tube), the plate current increases as the plate voltage is raised to about 8 volts, and any further increase of plate voltage does not bring about increased plate current. This shows us that at 8 volts the plate is drawing all the electrons the cathode can emit.

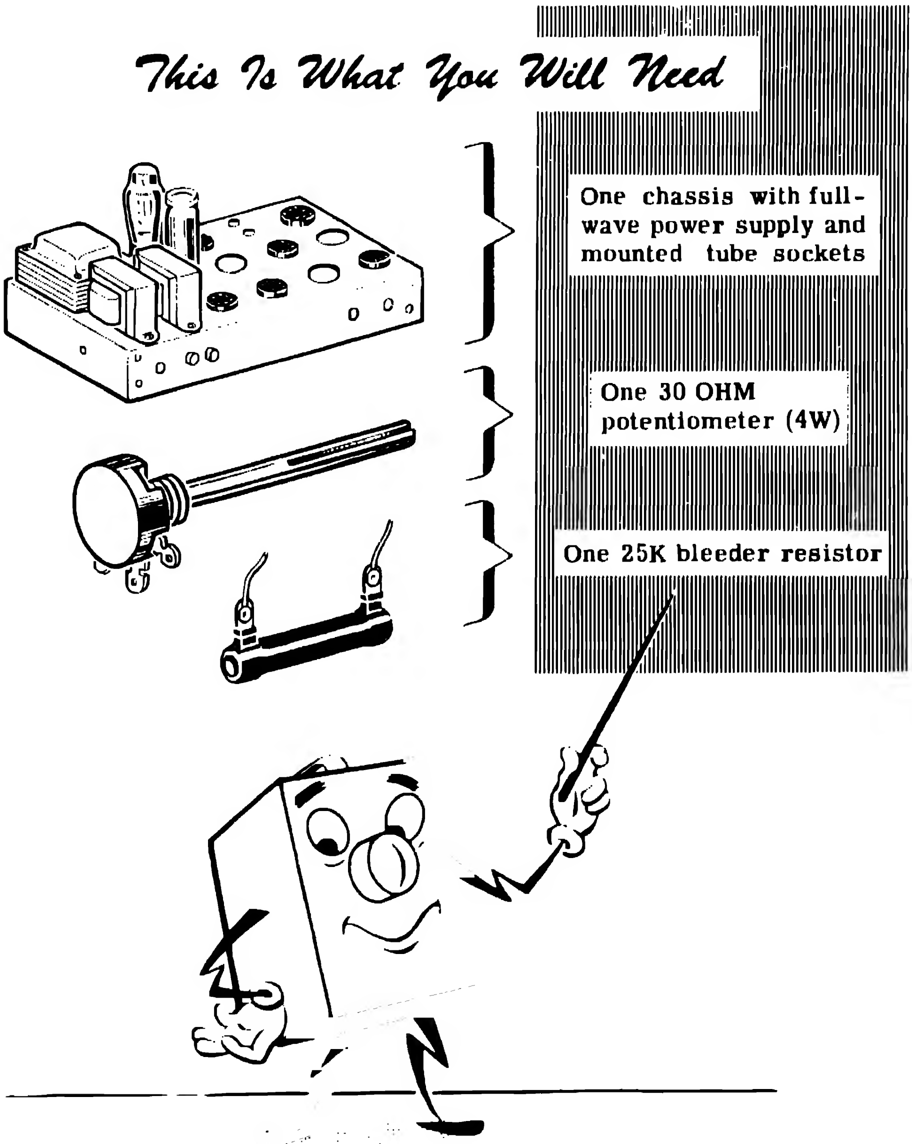
This undesirable restriction on the plate current which is due to limited cathode emission is called "saturation." Even in a fairly new tube working at rated filament voltage (6.3 volts), saturation would occur, but at a higher value of plate voltage. This would appear on the curve of 6.3 filament volts if higher values of plate voltage had been used.

CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Building a Diode Test Circuit

By now you should have a pretty good idea of how a diode operates, but you will understand this type of vacuum tube even better after you've worked with it. You are going to test a diode to see how the plate current is affected by the plate voltage. You will set up normal operating conditions for the tube, and you will observe various wave forms on the 'scope. When you finish you will get an opportunity to do some more troubleshooting.

The first thing you will do is build a diode test circuit onto your power supply.

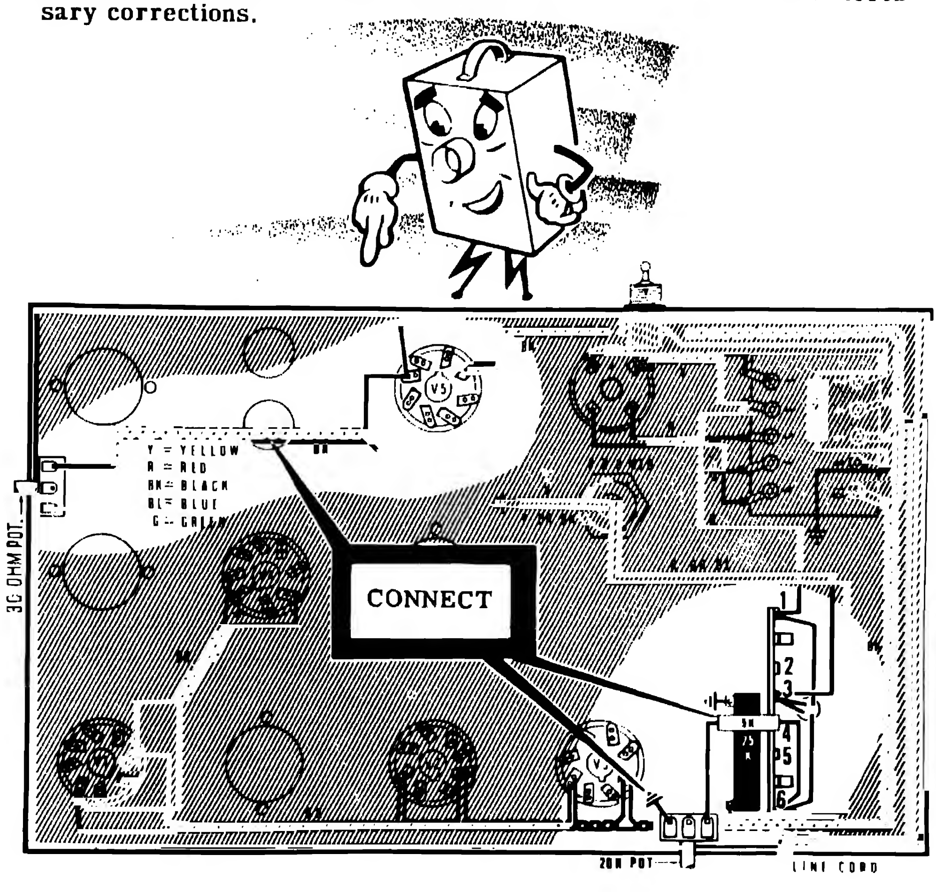


CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Building a Diode Test Circuit (continued)

Your power supply circuit will put out only one DC voltage of about 340 volts. In order to be able to change the B+ voltage, you will use the 20K potentiometer (called "Pot." for short). The 30-ohm pot. will be used to vary the tube filament voltage. The completed circuit is shown below. To get it this way, you will have to:

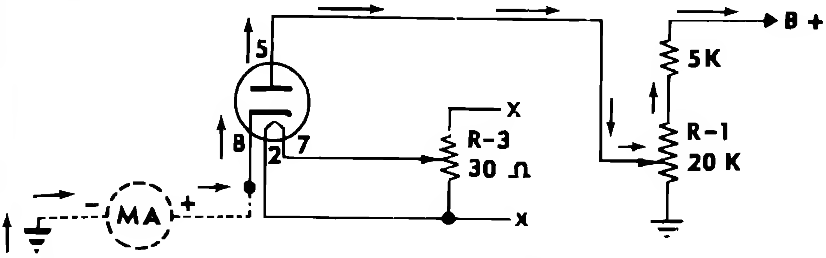
1. Connect the 25K bleeder resistor between lug 6 and ground.
2. Connect the 5K resistor between B+ (lug 6) and an outside terminal of the 20K pot.
3. Connect the other outside terminal of the 20K pot. to ground.
4. Mount the 30-ohm pot. as indicated in the diagram and connect a twisted pair of black leads from pins 2 and 7 of V-5 to the outside terminals of the 30-ohm pot. Check to see that heater leads are connected to pins 2 and 7 of V-5—if not, make these connections now.
5. Compare the chassis with the illustration below and make necessary corrections.



CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Building a Diode Test Circuit (continued)

Your next step is to wire up the tube socket V-4 using the circuit shown here.



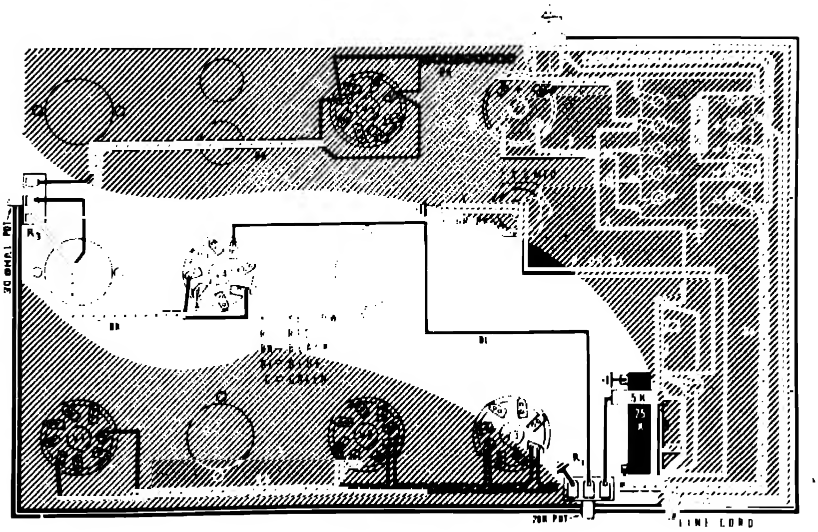
Potentiometer R-1 will supply the variable plate voltage necessary for the tests while the filament voltage is obtained from R-3.

The circuit is not complete as shown: to complete it, you will need to connect a milliammeter between the cathode (pin 8) and ground. The current will flow from ground through the meter to the cathode, from the cathode to the plate, and then from the plate through the power supply back to ground. No current can flow unless the electrons have a path to get to the cathode.

Follow the steps below, and your tube socket will be wired up in very short order.

1. Disconnect heater leads from pins 2 and 7 of V-4 if they are present. Replace these with a twisted pair of black wires connected between these pins and the center terminal and one of the outside terminals of R-3, the 30-ohm Pot.

2. Connect a blue wire between pin 5 (plate) and the center terminal of R-1, the 20K Pot. Your test circuit is now complete.

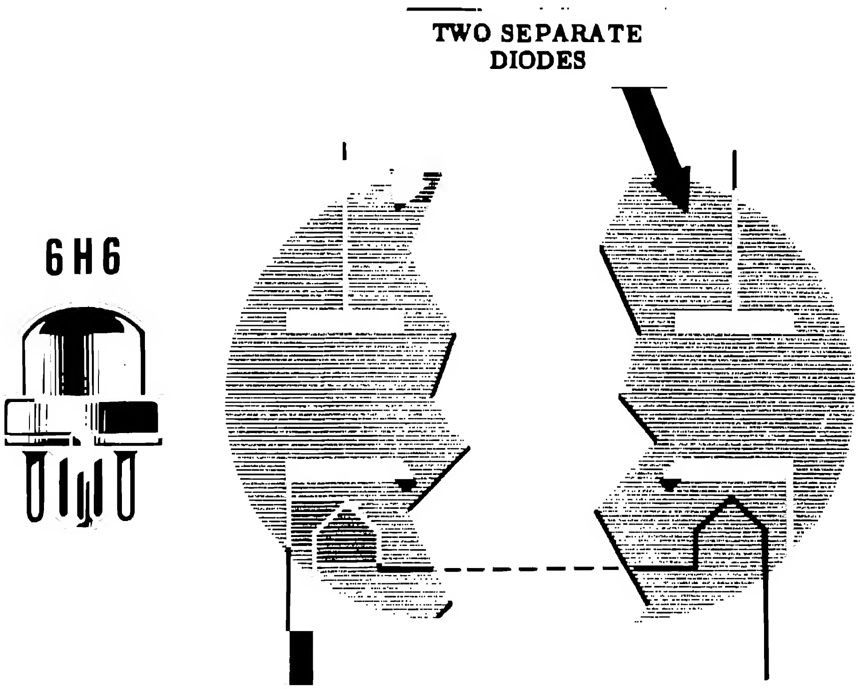


CHARACTERISTICS OF DIODE VACUUM TUBES

A Word about the Tube You Will Test

The first experiment you will perform will be with a type 6H6 vacuum tube, which consists of two diodes enclosed in one metal shell. The reason the 6H6 was chosen is that it is used more frequently than any other diode in Navy equipment. Don't be misled by its appearance—in spite of its small size, it's very dependable.

The two diodes which the 6H6 contains are identical and electrically independent of each other except for a common filament. In this way, one half of the tube can be used in one circuit while the other diode is used in a different part of the same or in a completely separate circuit. The main advantage of this arrangement is that it saves space in equipment.



There are several other multi-unit tubes which you will find in Navy equipment. In addition to the 6H6, there are tubes which have two completely separate units (such as the 6SN7), some which have three units with one common element (such as the 6SQ7) and many others. Whenever you want to know what a particular tube is like, refer to any standard tube manual. There you will see what type of a tube it is, how the elements are connected to the tube socket pins, what the heater voltage should be and a good deal more. Almost any question you might have about a tube will be answered for you in the tube manual.

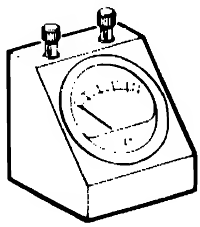
CHARACTERISTICS OF DIODE VACUUM TUBES

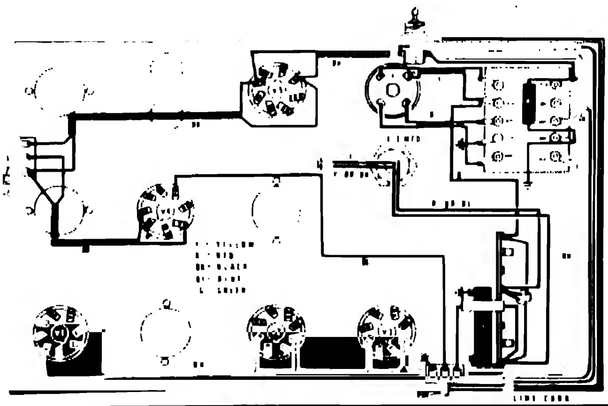
Demonstration—The Effects of Plate Voltage on Plate Current

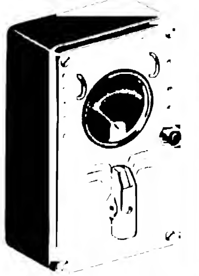
You have heard that increasing the plate voltage of a diode tube causes the plate current to increase. You have also heard that once the plate voltage is increased above a certain point, the plate current will no longer increase. The diode test circuit you have built makes it easy to apply various plate voltages to the tube, and it also has provisions for changing the filament voltage on the tube. The instructor will demonstrate just how the plate current changes when the plate voltage is raised—first when the filament voltage is 2 volts AC and then when the filament voltage is 6.3 volts AC.

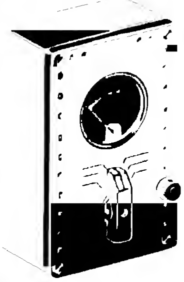
This Is What Is Needed

1. A power supply chassis complete with diode test circuit and 6H6 diode tube
2. One DC milliammeter
3. One AC voltmeter
4. One DC voltmeter









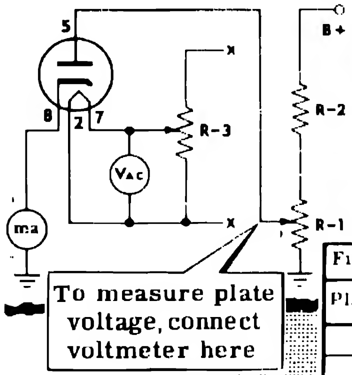
CHARACTERISTICS OF DIODE VACUUM TUBES

Demonstration—The Effect of Plate Voltage on Plate Current (continued)

First the instructor will demonstrate how plate current changes as the plate voltage is increased when there are 2 volts AC on the diode heater. The reason for using only 2 volts AC on the 6H6 filament is that saturation will occur at a fairly low plate voltage. With 6.3 volts on the filament it is necessary to put a high voltage on the diode plate in order to reach saturation.

The instructor will begin the demonstration by connecting the DC milliammeter into the cathode circuit of the 6H6 as shown in the diagram. Next he will place the AC voltmeter across the heater connections of the 6H6, and then he will adjust R-3 until the voltage across the heater is 2 volts AC. Finally the instructor will connect the DC voltmeter from the moving arm of R-1 to ground and adjust the potentiometer until the plate voltage is zero.

The plate voltage will be raised to 20 volts in two volt steps by adjusting R-1. The plate current will be measured for each of these steps and the results entered in a table such as shown in the illustration. The demonstration will prove that plate current rises with an increase of plate voltage, but above a certain point there will be no further increase in plate current in spite of a further increase in plate voltage.



THE EFFECT OF PLATE VOLTAGE ON PLATE CURRENT

Filament Voltage ________	
Plate Voltage	Plate Current
0	
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	

Filament Voltage ________	
Plate Voltage	Plate Current
0	
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	

The second part of the demonstration will repeat the first part except that R-3 will be adjusted to supply 6.3 volts AC to the diode heater. The results will show that increasing the filament voltage increases the cathode emission. This results in a much larger plate current before saturation is reached.

CHARACTERISTICS OF A DIODE VACUUM TUBE

Demonstration—The LO-3 Beat Frequency Audio Oscillator

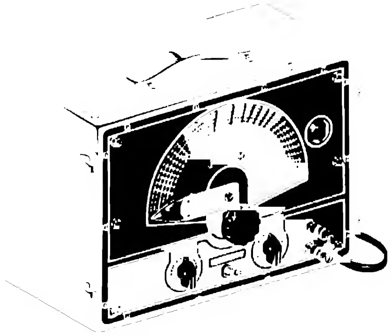
Up to now you have seen the instructor demonstrate what happens to plate current when plate voltage is increased. You have seen the saturation effect with DC voltages applied to a diode tube, and you are soon going to perform an experiment to observe the saturation effect when AC voltages are applied to the tube. In order to observe the saturation effect with AC applied to the diode, you will have to apply AC voltages of various amplitudes across the diode. One way to obtain AC at various voltages would be to use a variable transformer. Another way to obtain AC at various voltages and also at variable frequencies is to use a signal generator, also known as an audio oscillator. Since the signal generator is also an instrument that you will be using a great deal as soon as you begin working with amplifiers, it is a good idea for you to get acquainted with it now.

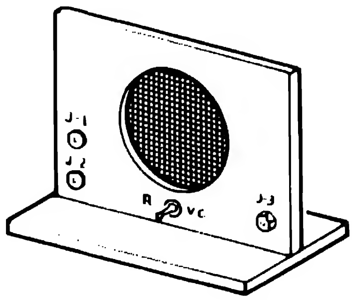
A signal generator is an electronic instrument which can put out AC voltages at various frequencies. In the future you will learn how a signal generator does this specialized job, but for the present it is enough for you to become acquainted with how it is used in testing and troubleshooting electronic equipment.

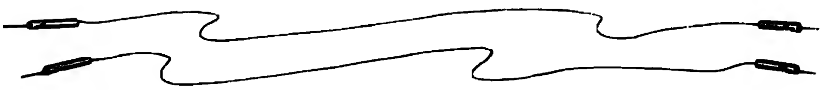
The instructor will demonstrate the use of the LO-3 Audio Signal Generator Controls and then he will show you what it can do.

This Is What Is Needed

1. LO-3 Beat Frequency Audio Oscillator (Signal Generator)
2. Speaker Test Panel
3. Two Test Leads







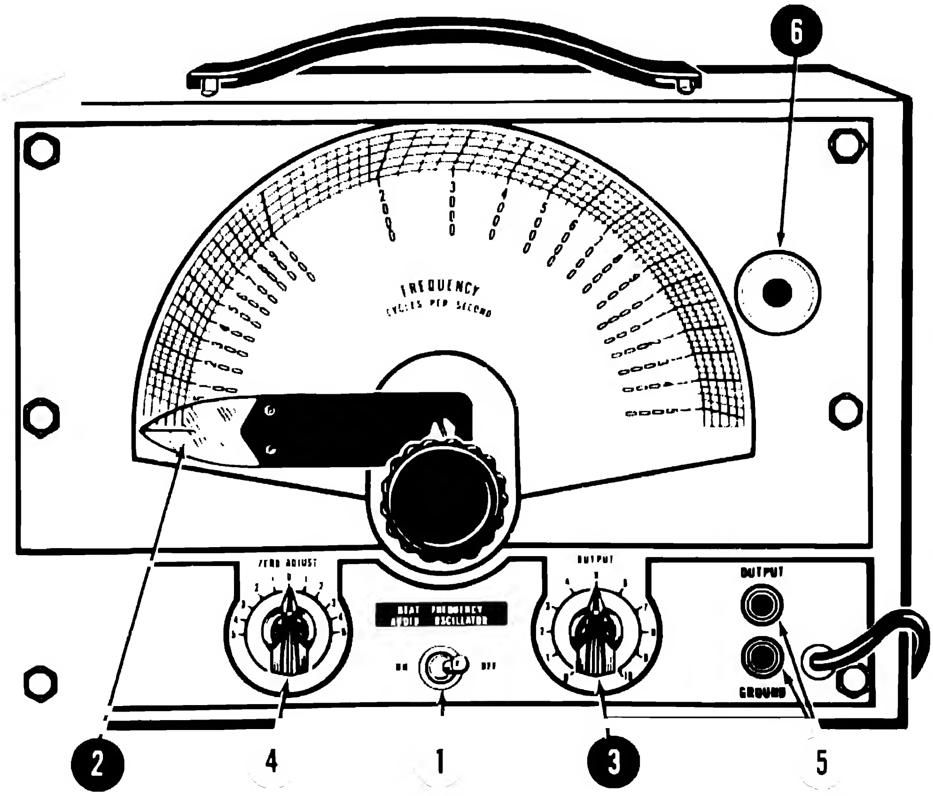
CHARACTERISTICS OF A DIODE VACUUM TUBE

Demonstration—The LO-3 Beat Frequency Audio Oscillator (continued)

The LO-3 is an instrument that can put out an AC voltage of from 0 volts to about 10 volts AC at any frequency between 0 and 15,000 cycles per second. Since these frequencies, if properly connected to a loudspeaker, can be heard by the human ear, the name "audio oscillator" or "audio signal generator" is applied to it.

The instructor will indicate the location and explain the use of the various controls:

1. ON-OFF switch — Used to turn the instrument on and off
2. FREQUENCY control — Used to adjust the frequency of the AC voltage coming out
3. OUTPUT control — Used to adjust the voltage of the AC coming out
4. ZERO ADJUST control — Used to adjust the zero cycle frequency point on the FREQUENCY scale so that the frequency of the AC output will be the same as indicated on the scale
5. OUTPUT and GND binding posts — Used to connect the AC voltage coming out to the point where this voltage is required
6. The "Electric Eye" tube on the upper right side of the panel is used in the "zero adjusting" procedure.



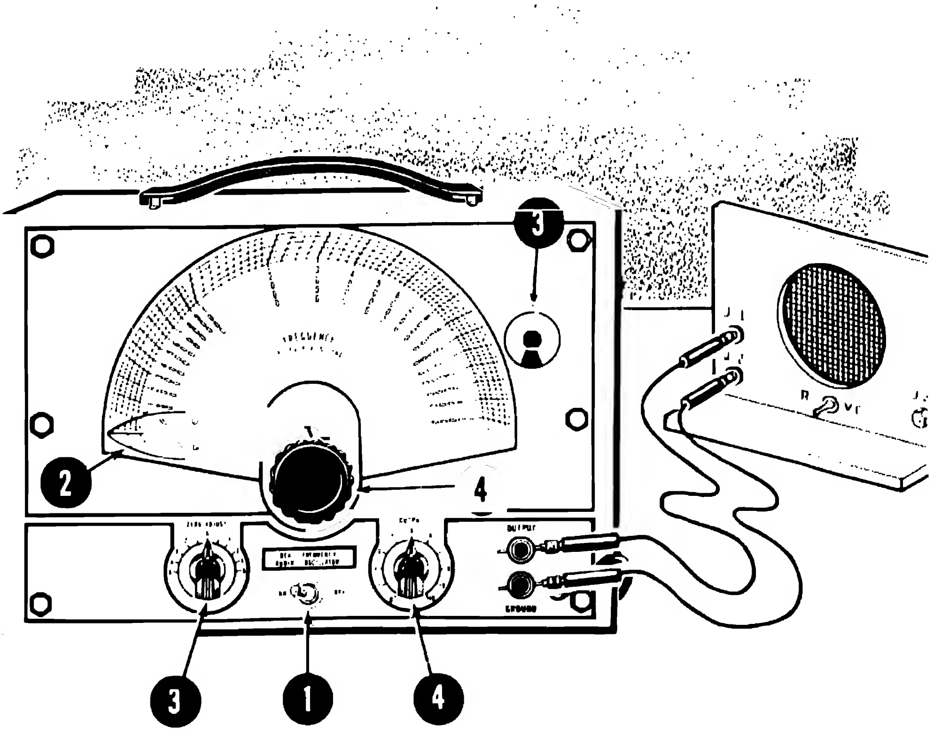
CHARACTERISTICS OF A DIODE VACUUM TUBE

Demonstration—The LO-3 Beat Frequency Audio Oscillator (continued)

Next the instructor will demonstrate the procedure required to put the instrument into operation:

1. Plug in the line cord and turn the ON-OFF switch to ON. Allow the instrument to warm up for at least two minutes before proceeding.
2. Turn the FREQUENCY control pointer to the ZERO ADJUST mark on the large dial.
3. Slowly turn the ZERO ADJUST knob until the "electric eye" tube flickers slowly and stops with a non-flickering shadow as shown in the illustration. The output of the instrument is now zero cycles and the frequency of the output will correspond very closely to any frequency to which the FREQUENCY control is set. The ZERO ADJUST control is kept at this setting as long as the instrument is in use.
4. Turn the FREQUENCY control to the frequency desired and turn the OUTPUT control until the desired amount of AC voltage appears at the OUTPUT and GND terminals.

The instructor will connect a speaker to the output of the LO-3. He will show you what the various frequencies sound like and he will demonstrate the effects of the OUTPUT control.



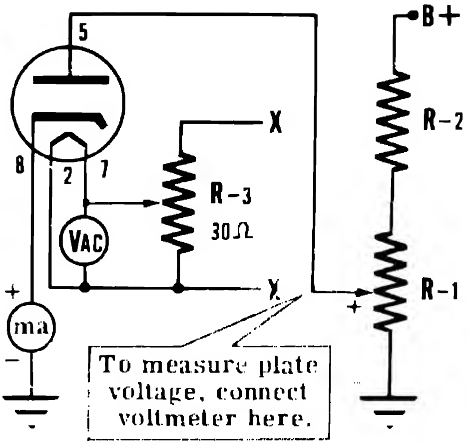
CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Testing a Diode Vacuum Tube

This Is What You Will Need

In addition to the circuit already wired in the chassis, you will need meters and vacuum tubes. These include:

1. Type 80 tube
2. 6H6 to be tested
3. 1K resistor
4. DC milliammeter
5. AC-DC voltmeter
6. Audio oscillator
7. OS-8A/U oscilloscope
8. Assorted test leads

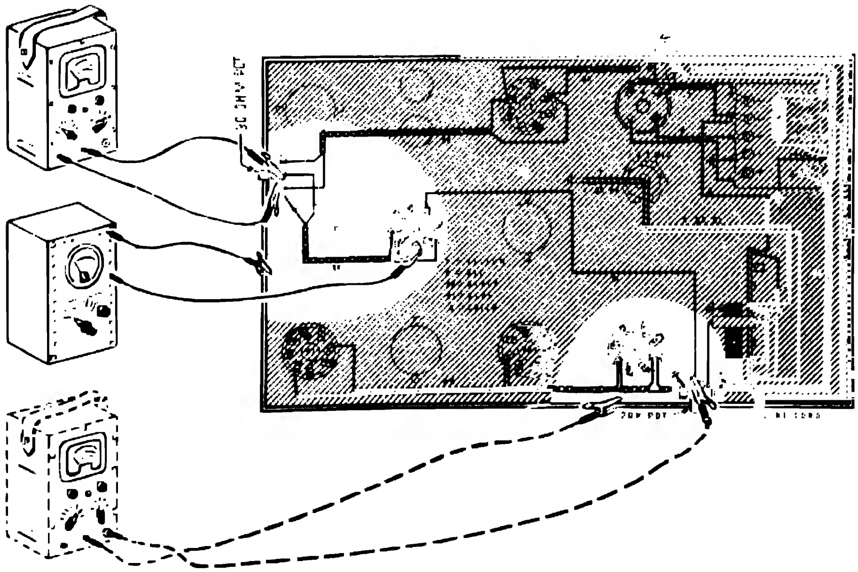


Connect the milliammeter with its negative probe clipped on the chassis (ground) and its positive probe connected to pin 3 (cathode).

Connect the AC-DC voltmeter as an AC instrument across the terminals of the 30-ohm Pot. (R-3). In this way, you will measure the voltage across the filaments (pins 2 and 7) of V-4.

When you are ready to measure plate voltage, you will remove the voltmeter from R-3, change it to a DC instrument, and connect it with the negative lead on the chassis and the positive probe connected to the center terminal of R-1, the 20K Pot.

Insert the 6H6 into tube socket V-4 and the type 80 into the rectifier socket.



CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Testing a Diode Vacuum Tube (continued)

1. Plug in the line cord (AC only) and turn on the power.
2. Adjust R-3 until the AC voltmeter (connected to R-3) reads 2 volts. Record your value of filament voltage in the "Table of Results."
3. Set up the voltmeter to measure the plate voltage (see previous sheet). Adjust R-1 until the DC voltmeter reads zero.
4. Read and record the plate current.
5. Set the plate voltage to 2 volts, 4 volts, and so on. At each voltage setting, record the plate current that flows at that value of plate voltage.
6. When you have taken all your readings at this low value of filament voltage, reset R-3 to supply 6.3 volts heater voltage. Repeat the experiment at this new value of heater voltage.

Table of Results

Filament Voltage ________	
Plate Voltage	Plate Current
0	
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	

Filament Voltage ________	
Plate Voltage	Plate Current
0	
2	
4	
6	
8	
10	
12	
14	
16	
18	
20	

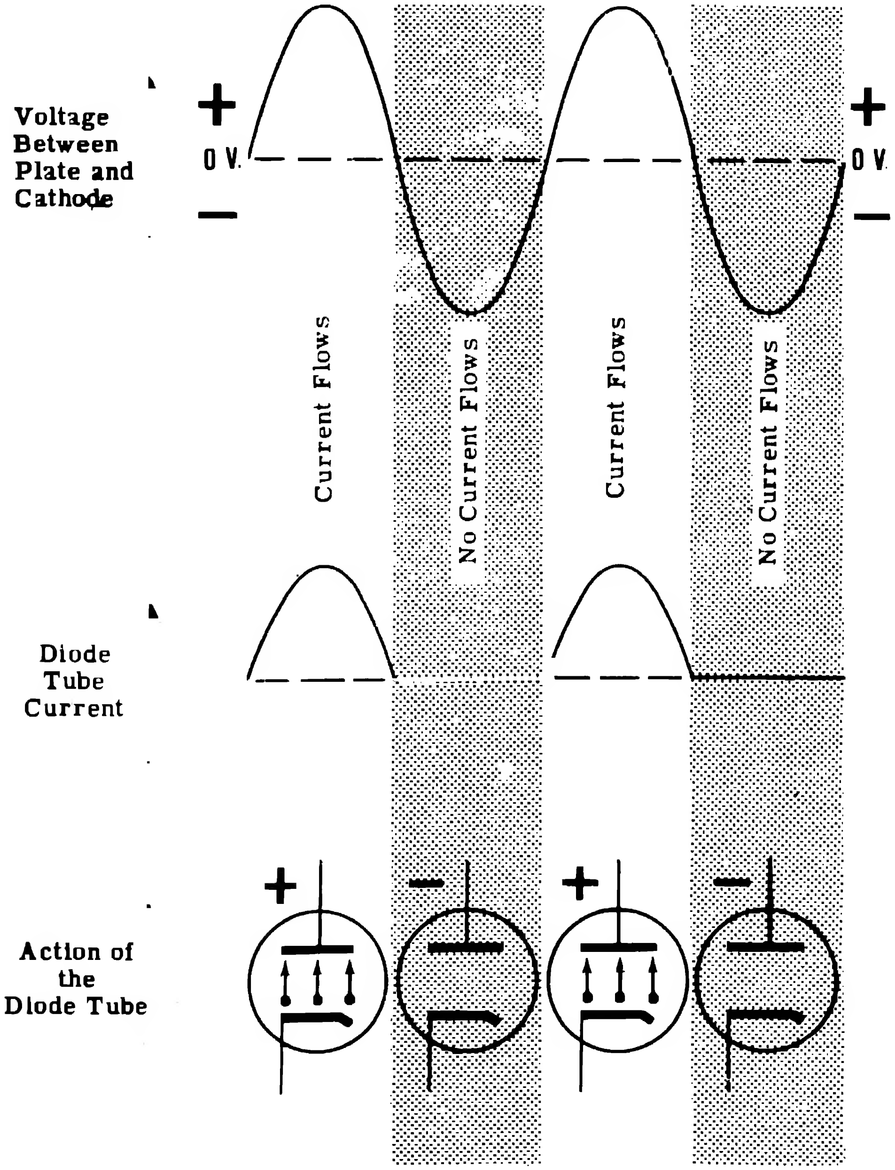
Compare your results with those shown graphically on sheet II-10-4. You should have detected the effects of saturation at the lower value of filament voltage. At the higher filament voltage, the tube should have operated almost the same as a resistor. If your tube was newer than the one used to obtain the data for the graph on sheet II-10-4, your current readings probably were higher than those shown. Similarly, if your tube had been older, your readings would have been lower. After you have finished the experiment remove the AC plug from the outlet.

CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Observing the Operation of a Diode

In normal use, diodes are seldom used with DC voltages; you have applied DC to the diode plate to test static (steady voltage) characteristics. You will need the information you have just obtained to explain what happens when normal operational conditions exist—that is, when AC is applied to the plate.

If an AC voltage is applied to the plate instead of a DC voltage, the tube will only conduct during that part of the AC cycle when the plate is more positive with respect to the cathode; no current flows in during a negative half-cycle. As a result, the diode will convert the AC voltage into a pulsating current which flows in only one direction.



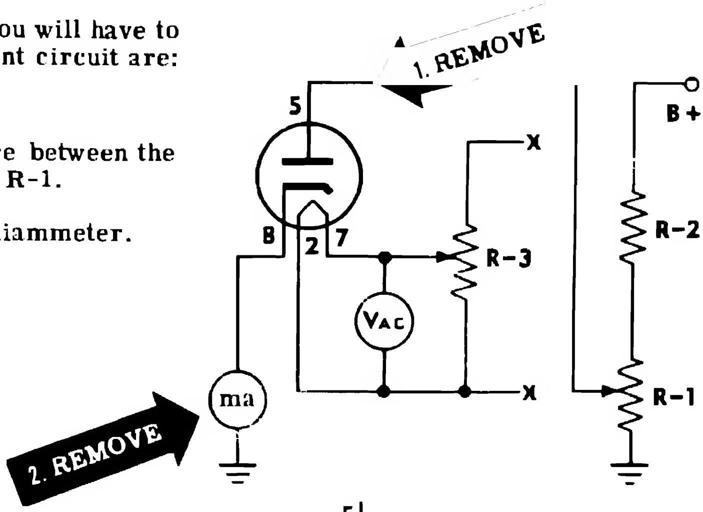
CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Observing the Operation of a Diode (continued)

The only changes you will have to make in your present circuit are:

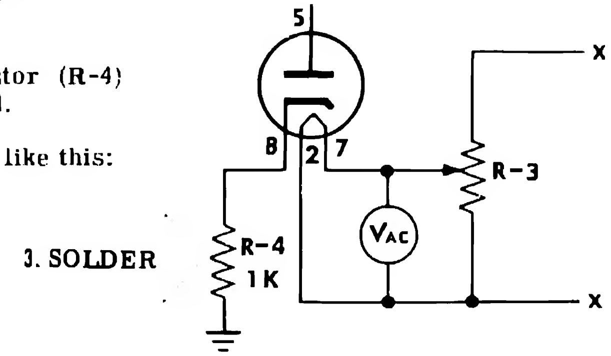
1. Remove the wire between the plate (pin 5) and R-1.

2. Remove the milliammeter.



3. Solder a 1K resistor (R-4) from pin 8 to ground.

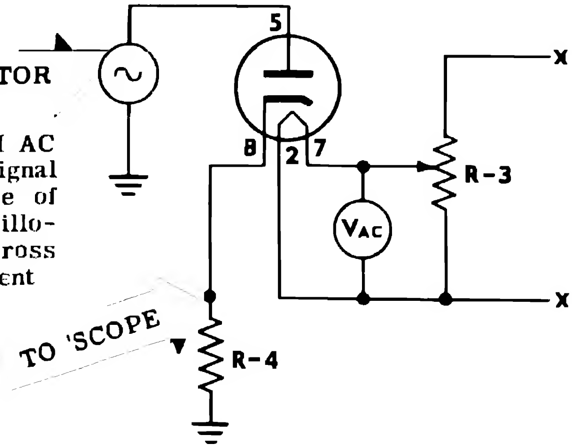
Your circuit now looks like this:



In many diode applications, a resistor such as R-4 is placed in the cathode circuit (or anywhere else in the circuit) where the diode current will flow through it. The voltage developed across this resistor is proportional to the current through it and is the useful output of the diode circuit. R-4 is known as the "load resistor."

OSCILLATOR

You will connect a source of AC voltage, an audio oscillator (signal generator), between the plate of the diode and ground. An oscilloscope will be connected across R-4 to show the diode current wave form.



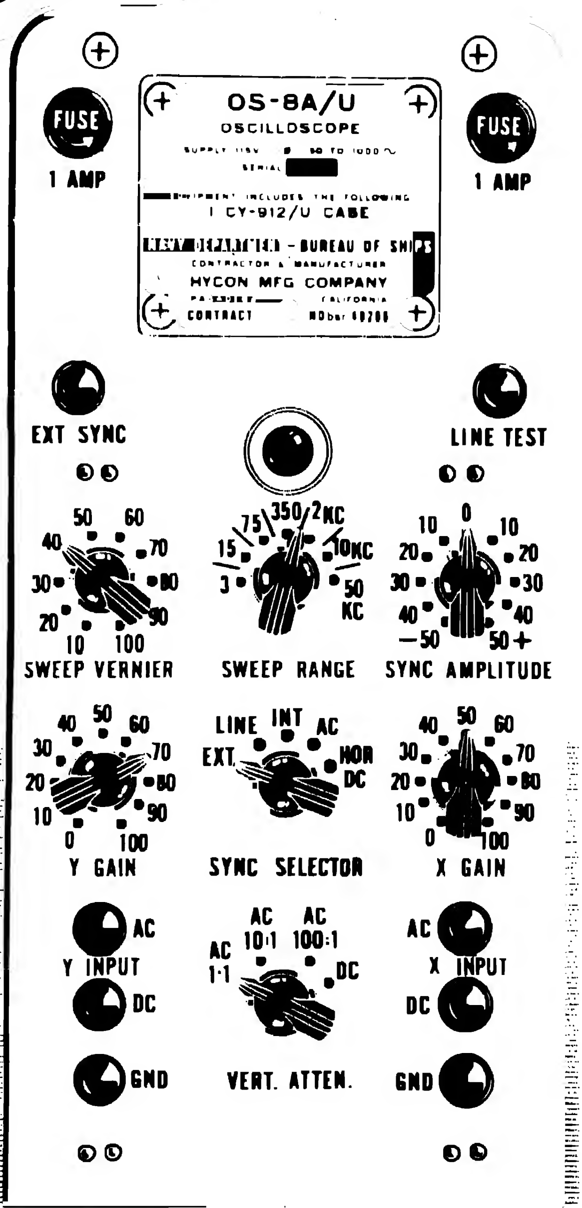
Experiment—Observing the Operation of a Diode (continued)

Setting up the Oscilloscope

1. Set your oscilloscope controls as shown in the illustration.

2. Plug the line cord into an AC source of about 117 volts. The 'scope can be used only with AC voltages in the range of from 104 to 126 volts.

3. Turn on the 'scope and allow about one minute for it to warm up. Then adjust the INTENSITY and FOCUS controls to get a thin, sharp trace line.



Experiment—Observing the Operation of a Diode (continued)

An audio oscillator is a signal generator (a source of AC voltages) which is very useful to a troubleshooter because its output frequency can be varied over the complete audio range—from 15 to 15,000 cycles per second.

If you are using an LO-3 audio oscillator (shown here), follow the instructions listed below for calibrating the dial. If you are using any other type of signal generator, instructions will be given by the instructor.

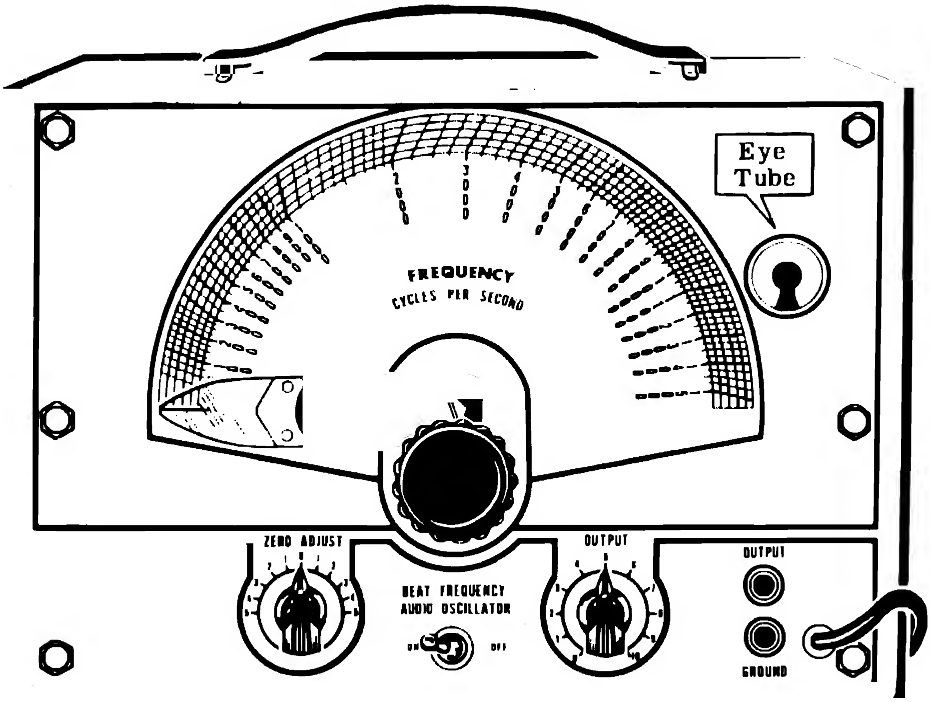
The signal generator must be adjusted so that the frequency output is zero cycles when the large pointer is turned to the ZERO ADJUST marker. If this were not done, the frequency coming out of the generator would not correspond to the markings on the large tuning dial.

1. Plug in the audio oscillator and turn the ON-OFF switch to "ON."

2. Turn the large tuning pointer to the ZERO ADJUST mark on the large dial.

3. **Slowly turn the ZERO ADJUST knob until the eye tube flickers slowly and stops with a non-flickering shadow as shown in the illustration. The eye tube is connected to the output of the generator and the shadow opens and closes in time with the frequency of the voltage changes. When the eye opens and closes slowly and then stops, you are at zero frequency.**

Without touching any other control, turn the large pointer to 1000 on the large dial. The output of your signal generator is now an AC voltage at a frequency of 1000 cycles per second.

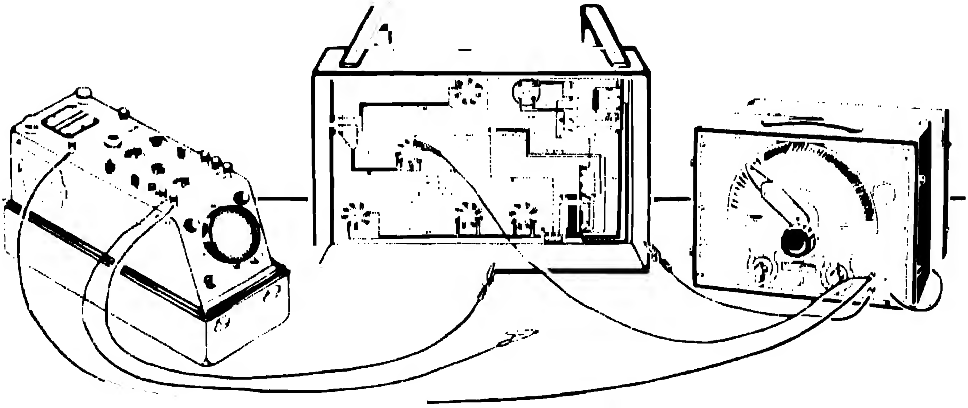


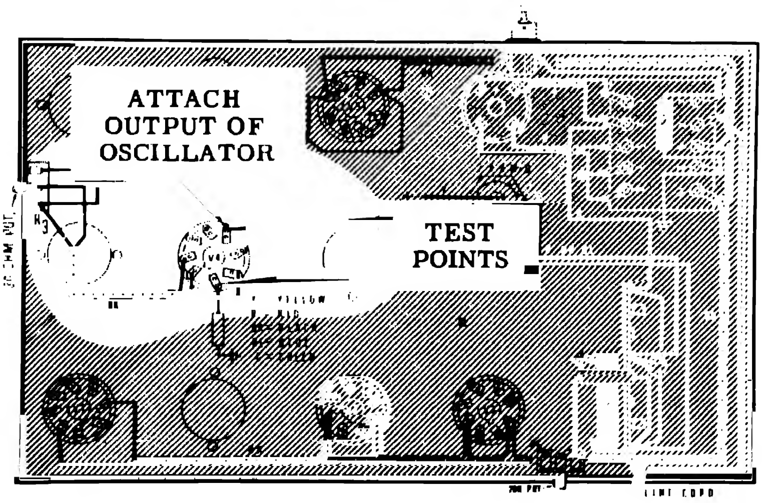
CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Observing the Operation of a Diode (continued)

In order to connect the audio oscillator and the 'scope to the diode test circuit:

1. Arrange the equipment as shown in the illustration. The chassis should be placed on its side or turned upside down so that the tube sockets can be conveniently reached.
2. Connect both the 'scope GND terminal and the low or GND terminal of the oscillator to the chassis with clip leads.
3. Connect the 'scope EXT SYNC binding post to the oscillator output terminal and switch the 'scope SYNC SELECTOR to EXT. You are using external synchronization because that will enable you to compare the phase relationship between the plate voltage (input) and the output voltage.
4. Attach an alligator-clip test probe to the 'scope Y INPUT terminal. By connecting this probe to the test points in the diode, you will be able to examine the signal on the 'scope screen.
5. Attach a clip lead from the oscillator output to pin 5 of the 6H6's tube socket. Set the output control on 10.

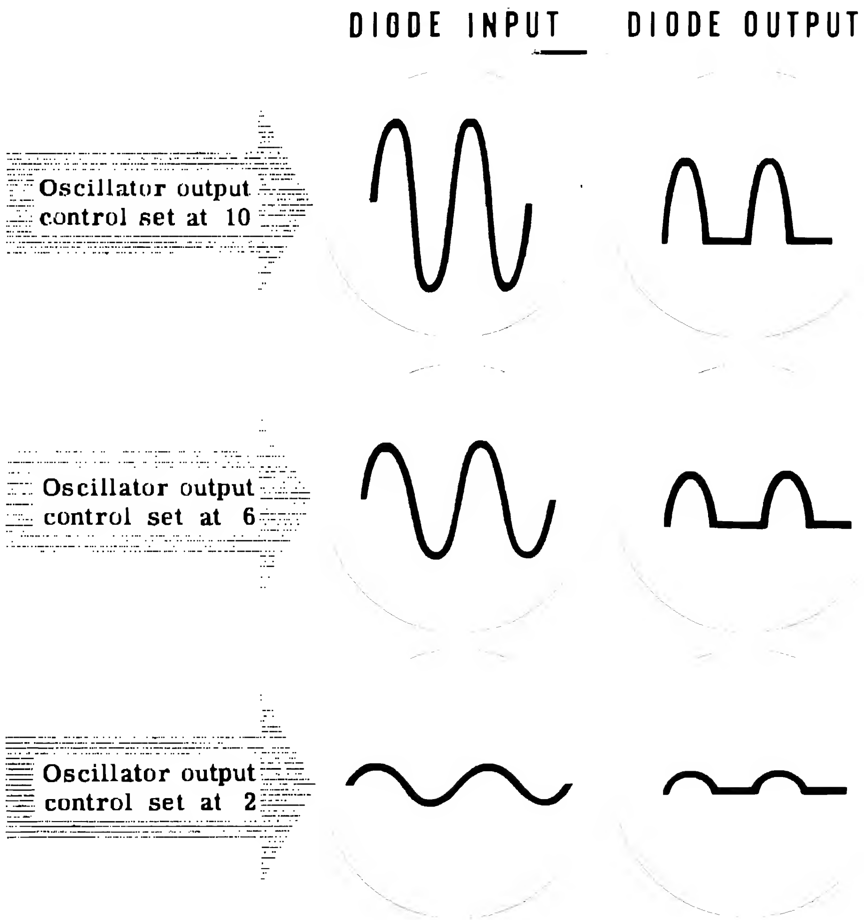




CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Observing the Operation of a Diode—Compare Diode Input and Output

1. Plug in the diode chassis, turn the power on, and adjust R_3 for a heater voltage of 6.3 volts.
2. Observe the input signal (output of the audio oscillator) by placing the 'scope's test lead on pin 5. Adjust the Y GAIN control to show a sine wave about 20 boxes peak to peak.
3. With the Y GAIN control left at the same setting as before, take the 'scope's test lead from pin 5 and place it on pin 8 where the output wave form will be seen.
4. With the output control of the oscillator set at 6, compare input and output voltage.
5. Repeat with oscillator output control at 2.

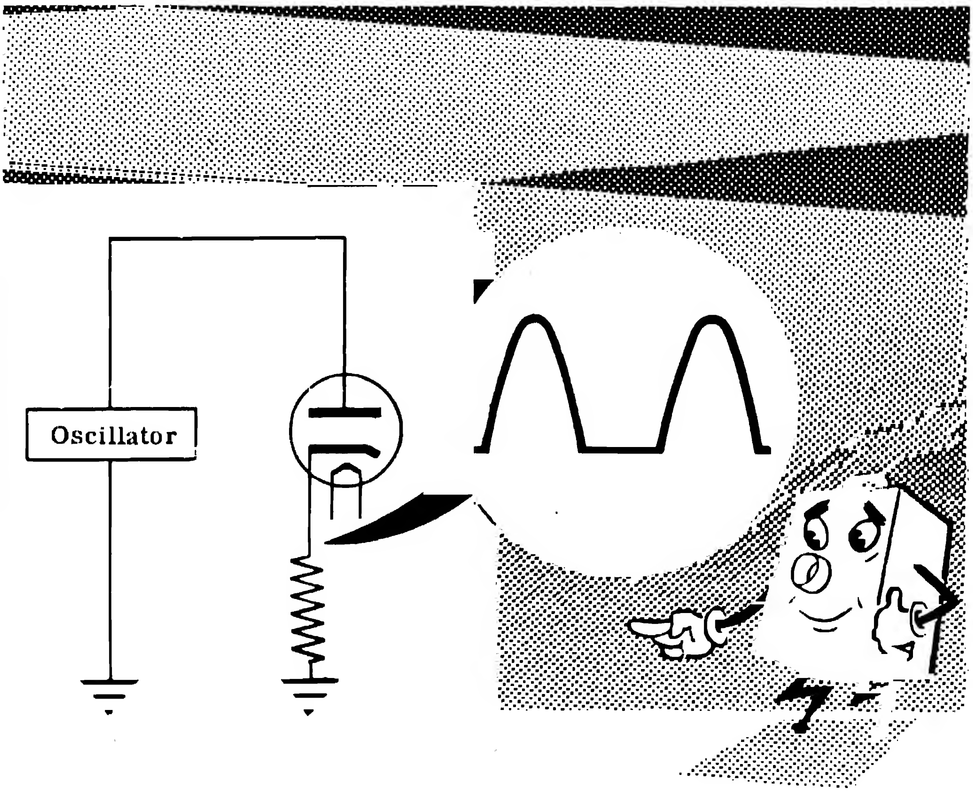


You have seen not only that the current is proportional to voltage but also that the diode current responds instantaneously to changes in voltage. You have just observed how a diode operates under normal conditions.

Experiment—Troubleshooting a Diode Circuit

Now if something goes wrong with the tube or its circuit, you can locate the source of trouble by examining the input and output wave forms. Your next step is to see how different troubles alter the 'scope patterns.

The requisite for effective troubleshooting is a knowledge of how the circuit operates and of the 'scope indications for normal operation. You should have both of these requirements as far as the diode circuit is concerned. If you don't see the wave form of a normally operating circuit, then the circuit is operating incorrectly and, needs repairing.



You are going to simulate a few defects that frequently occur in such a circuit and observe the change in the wave forms that each trouble produces.

Trouble No. 1: A Burned-out Filament

The first trouble you will duplicate in your diode is the one which causes most of the tube failures in actual equipment—a burned-out filament. To do this, you won't need a tube with an open filament; all you'll have to do is disconnect the lead going to pin 7 and no filament current will flow.

Now turn on the power and check the wave forms. Is the input wave form normal? Why did you fail to get any output across the 1000-ohm resistor, R-4?

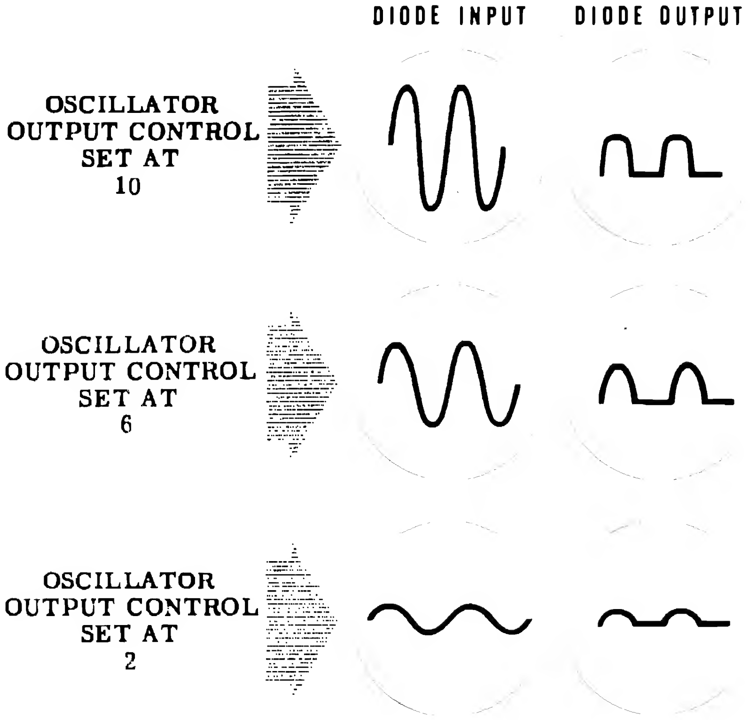
CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Troubleshooting a Diode Circuit (continued)

Trouble No. 2: Reduced Cathode Emission

Although a burned-out filament is the most common cause of tube failures, the filaments of some tubes outlast the tube's usefulness. As the tube is used, the emission from the cathode will eventually decrease. This decrease in emission, when severe enough, will necessitate changing the tube, and sometimes, depending on the circuit in which the tube is used, even a slight decrease in emission will affect the operation of the equipment.

To reduce the emission of your 6H6, lower the filament voltage to about 4 volts. Now, compare the 'scope picture of input and output wave forms when the audio signal generator's output is set at 2, 6 and 10 respectively.



You are observing the effects of saturation at the largest input voltage. If you saw this in actual equipment, the tube would be replaced by a new one and, if no improvement was noticed (very unlikely), the next step would be to check the filament voltage. In most pieces of Navy equipment, all the 6.3 volt filaments are connected in parallel across one transformer winding. The possibility that anything would go wrong with this supply is extremely slight.

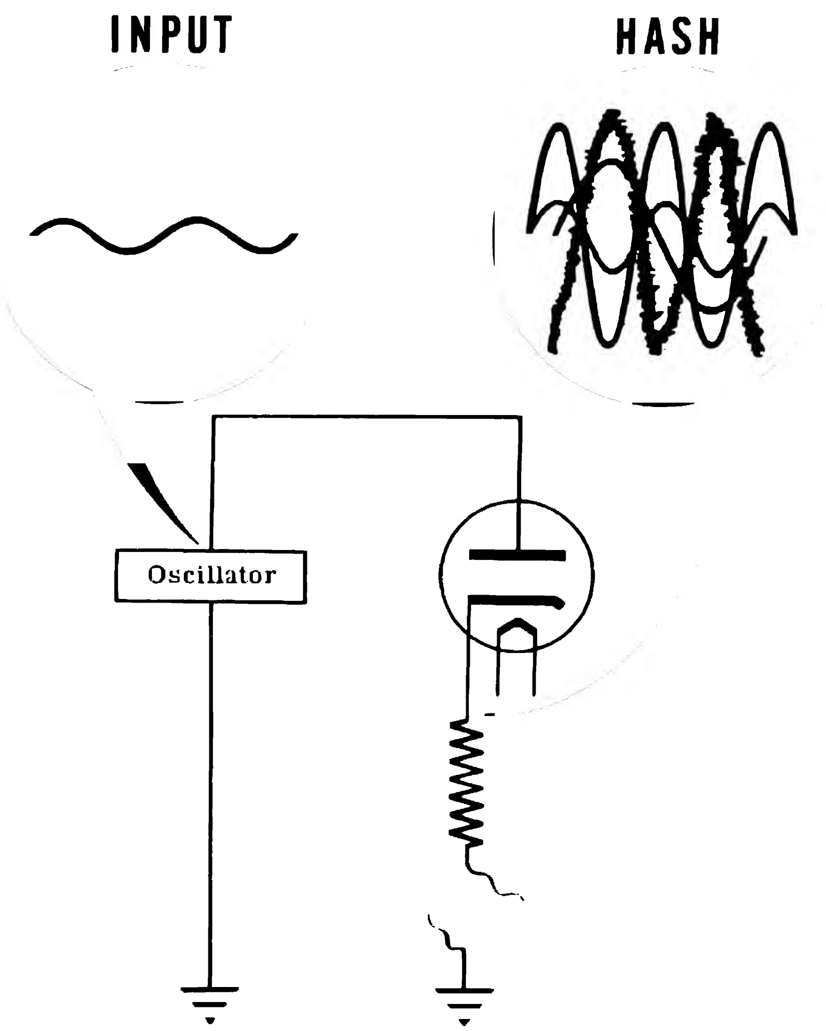
Another possibility is that the filament, its supply and cathode emission are normal, and that the plate voltage input is so large that the peaks of the voltage cause saturation. In this case, the trouble would not be in the diode circuit but in the circuit which supplies the voltage.

In any of these cases, the diode is said to be overdriven and its characteristic output has flattened tops.

CHARACTERISTICS OF DIODE VACUUM TUBES

Experiment—Troubleshooting a Diode Circuit (continued)

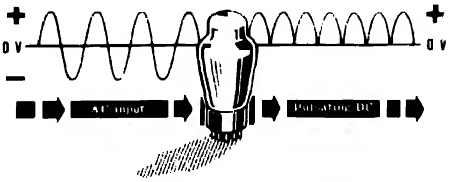
When you were reading about current flow in the diode circuit, you were told that a complete circuit was necessary in order to have current flow. Your next trouble is going to simulate what happens when a resistor burns out, or the leads connecting the cathode to the resistor, or the resistor to ground, break. To do this, simply unground R-4. Compare wave forms at pin 5 and at pin 8; the output setting of the oscillator is not important now.



What you are seeing on the 'scope is stray pick-up in the 'scope leads which is not the same frequency as the 'scope sweep and therefore, appears to be moving across the screen. Because of its scrambled appearance, this is known as "hash."

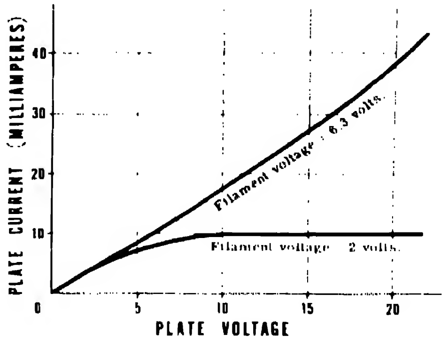
CHARACTERISTICS OF DIODE VACUUM TUBES

Review of Diode Characteristics



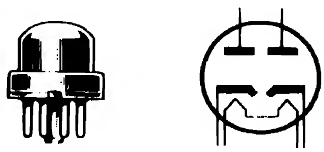
RECTIFICATION — A diode vacuum tube allows electron current to flow in only one direction—from the cathode to the plate. This effect permits AC voltage to be "rectified" into a pulsating DC voltage.

SATURATION — Plate current increases regularly as plate voltage is increased. When all of the electrons that can be emitted by the cathode are attracted to the plate, a further increase in plate voltage cannot attract any more electrons than are flowing already. When an increase of plate voltage fails to cause a rise in plate current, the tube is said to be "saturated."

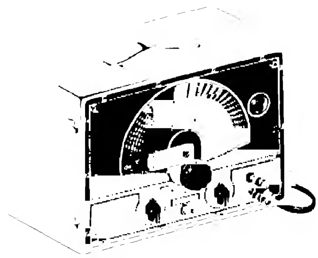


SATURATION AND FILAMENT VOLTAGE — Increasing the filament voltage increases the filament temperature—resulting in a hotter cathode. The more heat the cathode gets, the more electrons will be emitted from its surface. When the cathode emits more electrons, the saturation point will not occur until the plate voltage reaches a much higher value. Note that the filament voltage cannot be increased beyond the limits stated in Manufacturers Tube Manual, otherwise the filament will burn out.

MULTI-UNIT TUBE — A tube which contains within its envelope the elements of several complete tubes. The 6H6 contains the elements of two diode tubes—each of which has a plate and a cathode, and each cathode is heated by part of a single heater or filament.



AUDIO OSCILLATOR — A test instrument which will put out AC voltages at audio frequencies (15 to 15,000 cycles per second).

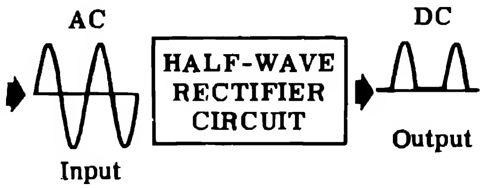


POWER SUPPLIES

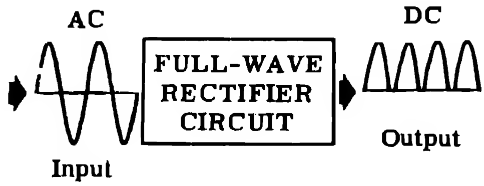
Review of Power Supplies

Before you leave the study of power supplies and go on to learn about amplifiers, suppose you review some of the important things you've found out about power supplies and their components.

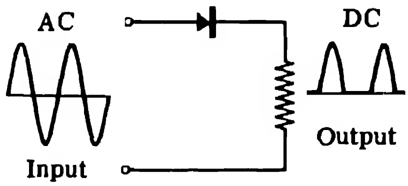
<u>HALF-WAVE RECTIFICATION</u> — Changing the positive cycles of an AC voltage to pulsating DC by allowing current to flow through a circuit in one direction only.



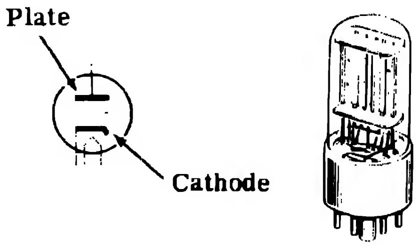
<u>FULL-WAVE RECTIFICATION</u> — Changing both cycles of AC to pulsating DC.



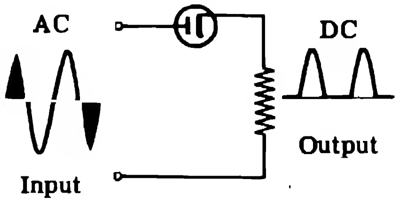
<u>DRY METAL HALF-WAVE RECTIFIER</u> — A circuit which produces half-wave rectification by using a device consisting of two metallic plates which conduct current flow in only one direction.



<u>RECTIFIER TUBE</u> — A vacuum tube diode consisting of plate and cathode which allow electron flow only from cathode to plate and thus acts as a rectifier.



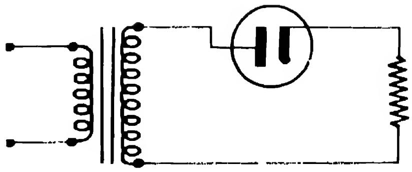
<u>VACUUM-TUBE RECTIFIER CIRCUIT</u> — A diode vacuum tube connected in series with an AC voltage source to change AC to DC.



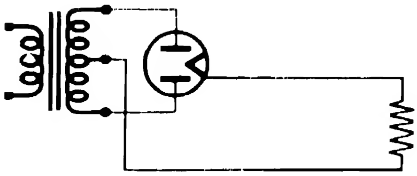
POWER SUPPLIES

Review of Power Supplies (continued)

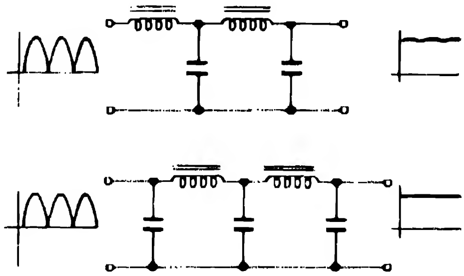
<u>TRANSFORMER TYPE HALF-WAVE RECTIFIER</u> — A circuit which uses a transformer to supply high-voltage AC to a vacuum tube rectifier, which then rectifies it to pulsating high-voltage DC.



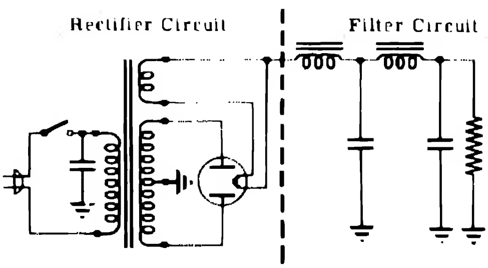
<u>FULL-WAVE RECTIFIER CIRCUIT</u> — A circuit which uses a transformer and a full-wave rectifier diode to produce full-wave rectified pulsating DC from an AC input.



<u>FILTER CIRCUITS</u> — Circuits consisting of inductors and capacitors used to change pulsating DC output of a rectifier to pure DC.



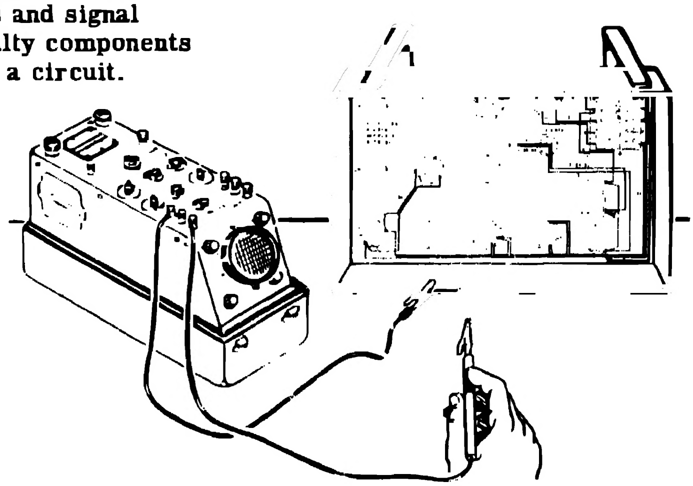
<u>COMPLETE POWER SUPPLY</u> — The complete circuit consisting of full-wave rectifier and filter circuits, used to supply high DC voltage to other circuits.



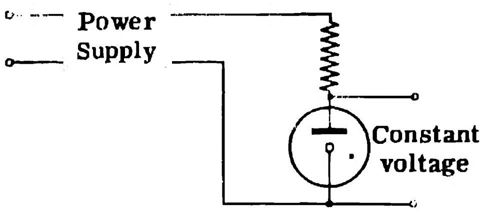
POWER SUPPLIES

Review of Power Supplies (continued)

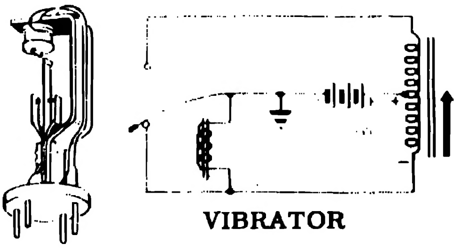
TROUBLESHOOTING — The proper use of visual checks and signal tracing to locate faulty components or other troubles in a circuit.



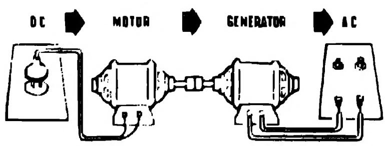
VOLTAGE REGULATOR CIRCUIT — A circuit which uses a gas-filled diode to maintain constant output voltage. The voltage across tube terminals remains constant over a large range of source voltage or load current changes.



OTHER POWER SUPPLIES — Transformerless and chokeless power supplies, vibrators, motor-generators, dynamotors and rotary converters are other types of power supplies used to fill special requirements as to size, weight, power source available and load requirements.



VIBRATOR



MOTOR-GENERATOR

Now you have learned all you need to know about power supplies. The power supply you have built will be used to supply power to all of the other circuits you will study. Let's go on to find out about the first of these circuits—amplifiers.